EMPOWERING THE FRONT-SEAT PASSENGER: DESIGN AND EXPERIENCE PROTOTYPING OF LUXURY INFOTAINMENT SYSTEMS THROUGH VR SIMULATION

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ABSTRACT

EMPOWERING THE FRONT-SEAT PASSENGER: DESIGN AND EXPERIENCE PROTOTYPING OF LUXURY INFOTAINMENT SYSTEMS THROUGH VR SIMULATION

Guzin Sen

Automotive user interfaces have been designed within the limitations of driving activity. Therefore, there has been a lack of infotainment solutions that target the front-seat passenger as another car occupant with his/her own needs, interests and capabilities. This research is built on the motivation of empowering the front-seat passengers in luxury car journeys through infotainment systems. It handles front-seat passenger's empowerment through the investigation of how a pleasant and luxury infotainment experience is manifested via new functionalities and interactions.

This research tackles the challenge of understanding how these unprecedented infotainment solutions will add to front-seat passenger's travel experience with experience prototyping through VR simulation. It follows the 'research through design approach' by i) presenting a design proposal for the front-seat passenger infotainment system, ii) developing a VR simulation to communicate the infotainment system interactions within a travel scenario in an immersive way, and iii) conducting experience prototyping study where participants reflect on the design proposal (VR simulation) through administration of mixed data collection methods including semantic differential questionnaires and semi-structured interviews.

To achieve the above-mentioned objectives, the research makes use of an extensive literature on User Experience (UX)-Human Computer Interaction (HCI), Automotive UX, Luxury Marketing, and Simulation. The synthesis of the UX and marketing literature enables deconstruction of pleasant and luxury user experience into a set of qualities/metrics to be referred in design and design evaluation. The synthesis of aesthetics of interaction studies in the UX literature helps to categorize the diverse aspects of the infotainment system. The analysis of the academic and industrial efforts to empower front-seat passengers through automotive user interfaces is used for identification of promising technologies and trends for the infotainment system. The literature review on experience prototyping with VR constitutes a reference in prototyping-related decisions and using VR as part of the user study.

The thesis finally presents the analysis of the experience prototyping study through i) the quantitative representation and discussion of the diverse aspects of the infotainment system (functionalities and interaction aesthetics) that play role in delivery of the various qualities of luxury experience, ii) structured analysis of the participants' suggestions for the system with specification of the underlying motivations and iii) development of a framework that conceptualizes the front-seat passengers' changing role and relations with the infotainment system. Based on these investigations of the link between the infotainment system aspects and the participants' expectations/concerns, the research concludes with key design considerations and recommendations for the future (luxury) front-seat passenger-oriented infotainment system solutions. It also presents recommendations for integration of VR simulation into future car HMI appraisals by reflecting on the experience prototyping study conducted as part of the PhD research.

DECLARATION

I hereby confirm that I have read and understood the University's PGR Policy on Plagiarism and Dishonest Use of Data, acted honestly, ethically and professionally in conduct leading to assessment for the programme of study; I have not copied material from another source nor committed plagiarism nor fabricated, falsified or embellished data when completing this document, nor colluded with any other student in the preparation and production of this material. I have cited all materials and results that are not original to this work.

Güzin Şen

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LIST OF ABBREVIATIONS

AR: Augmented Reality

GT: Grand Tourer

GUI: Graphical User Interface

HMD: Head-mounted Display

HMI: Human-Machine Interaction

HCI: Human-Computer Interaction

HUD: Head-up Display

PQ: Presence Questionnaire

SSQ: Simulator/Simulation Sickness Questionnaire

TOLED: Transparent Organic Light-Emitting Diode

UI: User Interface

UX: User Experience

UXQ: User Experience Evaluation Questionnaire

VE: Virtual Environment

VEC: Virtual Engineering Centre

VR: Virtual Reality

CHAPTER 1.

INTRODUCTION

This research investigates the front-seat passenger's travel experience in a luxury car within the scope of the infotainment system. In-vehicle **infotainment systems** are the parts of automotive HMI (human-machine interface) / automotive user interfaces that provide 'information' and 'entertainment' services (e.g. navigation, media player) to car occupants. Based on the latest infotainment systems provided by the luxury automotive manufactures (e.g. BMW-iDrive, Bentley Motors Infotainment, Jaguar-Incontrol, MercedesBenz-Command) the basic functionalities / infotainment features that are provided in these systems can be compiled as navigation, media, radio, telephone, settings, and vehicle information. Most of these systems are placed in central dashboard/console and the front-seat passengers have a partial access to the controls and displays. However, since the driver is / has been the main controller of the car, the infotainment features and interactions have been traditionally designed within the limitations and complexity of the driving activity. This resulted in infotainment systems that neglect front-seat passengers who have their own infotainment needs and interests within this shared experience of mobility. The front-seat passengers may spend as much time in the car being driven around but without having the means that are specialized to keep them informed and entertained. Whilst travelling, the front-seat passengers have fewer distraction issues and they can concentrate on more varied stimuli. Their physical access to diverse parts of the car interior is also not as limited as that of the driver.

Such opportunities encourage us to rethink the way passengers interact with the infotainment system and to enrich the infotainment features in the car. As stated in the title, in this research, this motivation is defined as **empowering front-seat passengers**, which means increasing their involvement in the car journeys by providing them means that will add both pragmatic and hedonic values to their travel experience.

Although there are academic and industrial efforts to design and develop front-seat passenger-oriented infotainment systems, they are either at concept level or very limited in commercial applications. Before making investments to realize these efforts in production cars, it is important for car manufacturers to understand how the front-seat passengers will approach to these unprecedented solutions and what their concerns about / further expectations from these infotainment system proposals would be. This is where **experience prototyping through (VR) simulation** plays a significant role.

Experience prototype is defined by Buchenau and Suri (2000, p.425) as:

> …any kind of representation, in any medium, that is designed to understand, explore or communicate what it might be like to engage with the product, space or system we are designing.

There is a number of medium options for prototyping interactive systems, ranging from paper prototypes to digital simulation. For investigating the ways infotainment system enrich the front-seat passenger's travel experience, prototyping should not be limited to communication of the steps of interaction or usability appraisals of a set of infotainment tasks. It should also investigate the role of interaction aesthetics (e.g. response time) and new functionalities in the delivery of a pleasant user experience. Therefore, prototyping should integrate interactivity and programmability, which justifies the need of a digital tool. Nevertheless, while selecting the digital tools to prototype user experience, the researchers cannot handle front-seat passenger infotainment system only as a (graphical) user interface since it is also a component of the car interior and the front-seat passenger's overall travel experience. Therefore, an immersive simulation emerges as a promising prototyping medium to understand and explore what it would be like to interact with the infotainment system within the car (e.g. the spatial aspects) and within a travel scenario (e.g. the context of travel, the surroundings) as a front-seat passenger.

This research has two main partners, which are 1) Bentley Motors and 2) Virtual Engineering Centre (the VEC). The reason why this PhD research is conducted in collaboration with these two partners is 1) to address the above-mentioned problem areas within the real scenarios and industrial motivations, and 2) to explore the solutions to these problems through experience prototyping with simulation. The collaboration with Bentley Motors adds another dimension to the research motivation of empowering front-seat passengers through design and experience prototyping of infotainment systems, which is investigation of **luxury** experience. More information about the partnerships will be offered in the following sections.

1.1 Aim

Having explained the multi-faceted problem area and opportunities to be tackled within the scope of the PhD research, the aim of this research can be defined as **"To investigate the experience dimensions of luxury infotainment systems that will empower front-seat passengers through experience prototyping with VR simulation",** which will inform the design of the future front-seat passenger infotainment systems.

1.2 Objectives

To achieve the main aim of the research, there are three objectives to be accomplished consecutively:

- **O1:** design and development of a front-seat passenger infotainment system proposal based on the investigation of promising interactions and functionalities
- **O2:** communication of the design proposal with the appropriate prototyping tools and simulation technologies
- **O3:** execution of the user studies to investigate the user experience of the design proposals through prototyping

1.3 Research Questions

The following questions are set to achieve the main aim and objectives of the research:

RQ1: How can the qualities of luxury user experience be manifested via different aspects of front-seat passenger infotainment systems?

> **RQ2:** What metrics define a pleasant user experience; how does the concept of luxury relate to these metrics?
>
> **RQ3:** What are the specific qualities of experience that define the front seat passenger's expectations from the infotainment system; why do front-seat passengers appreciate particular aspects of the front-seat passenger infotainment system as luxury?
>
> **RQ4**: When the front-seat passenger infotainment system is considered as an interactive system, how can user interactions with the system be deconstructed into separate elements?

RQ5: How can interaction technologies be used to deliver (new) infotainment functionalities and interactions to empower front-seat passengers?

RQ6: How can simulation technologies be used to explore front-seat passenger infotainment concepts? What are the specifications of the experience prototyping tool-methodology to appraise the user experience of the front-seat passenger infotainment system?

RQ 2 ,3, and 4 are asked to deconstruct i) luxury user experience and ii) front-seat passenger infotainment systems that are mentioned in RQ1 further. Such deconstruction is also crucial for the achievement of the third objective, since it reveals the metrics for (luxury) user experience evaluation and enables doing this evaluation with reference to diverse aspects of the infotainment system. RQ5 has a strong connection with the first objective of the research, which is design and development of a front-seat passenger infotainment system proposal based on the investigation of promising interactions and functionalities. RQ6 focuses on the methodology of the research, which makes use of experience prototyping with VR simulation (objective 2 and 3) to answer RQ1 and to achieve the main aim of the PhD research. Table 1.1 shows the studies or phases of the PhD research where each research question is answered (the relevant chapters-sections of the thesis).

Table 1.1 Studies or phases of the PhD research, where each research question is answered.

RQ	Study / phase of the PhD research	Chapter/section
RQ1	Experience prototyping of the front-seat passenger infotainment system through VR Simulation	Chapter 5
RQ2	Literature review - Deconstructing the WHY: The qualities of user experience	Section 2.2
	Literature review - The concept of luxury and luxury values	Section 2.3
RQ3	Experience prototyping of the front-seat passenger infotainment system through VR Simulation	Chapter 5
RQ4	Literature review - Deconstructing the HOW: The aspects of (aesthetics of) interaction, Deconstructing the WHAT	Section 2.2
RQ5	Literature review - Contemporary automotive infotainment solutions to empower front-seat passengers	Section 2.4
	Focus group: Exploration of the simulation challenges of interaction technologies (with the VEC)	Section 4.2
	Concept development of the front-seat passenger infotainment system	Section 4.3
	Design detailing and simulation development	Section 4.4
	Experience prototyping of the front-seat passenger infotainment system through VR Simulation	Chapter 5
RQ6	Literature Review - Deconstructing the HOW: The aspects of (aesthetics of) interaction, Deconstructing the WHAT	Section 2.2
	Literature Review - Experience Prototyping with VR	Section 2.5
	Focus group: Exploration of the simulation challenges of interaction technologies (with the VEC)	Section 4.2
	Design detailing and simulation development	Section 4.4
	Experience prototyping of the front-seat passenger infotainment system through VR Simulation	Chapter 5

1.4 The Methodological Approach

Chapter 3. Methodology presents an overview of the methods followed to tackle the research questions. The methodological approach of the PhD research can be summed up as “research through design”, which is defined by Zimmerman et al. (2010, p. 310) as “a research approach that employs methods and processes from design practice as a legitimate method of inquiry”. (See also Archer, 1995). The infotainment system proposal that will be designed and developed throughout the research can be regarded as a concrete means of discussion, which would help us investigate what designers need to consider while developing solutions to empower front-seat passengers through luxury infotainment systems. This discussion was made possible with the development of the simulation to be used in the user study / experience prototyping.

As can be seen in Table 1.1, most of the research questions are answered through a series of studies/phases of the PhD research, by synthesizing the findings of the literature review within design & simulation of the front-seat passenger infotainment system and the analysis of the data collected in the user study. The details of the studies/phases of the PhD research can be found in Section 1.6 “Breakdown of the Chapters” as well as in Chapter 3. “Methodology”.

The following section will give further details about the research partners, their role in the PhD research and expected contributions of the research to the research partners.

1.5 The Research Partners

The PhD research is conducted in collaboration with two partners: the VEC (Virtual Engineering Centre) and Bentley Motors. The two partners had a history of working together, so the PhD research benefited from existing staff relations and prior experiences of the partners. The scope of the research is defined by understanding the overlapping motivations of both research partners, which can be summarised within the contemporary design and prototyping issues in the automotive industry. These issues are:

- lack of front-seat passenger-oriented infotainment solutions
- lack of virtual prototyping tools to appraise automotive HMI systems (e.g. infotainment)

Bentley Motors: Bentley Motors is a British luxury car manufacturer with its brand heritage dating back to the 1920s. They have been producing cars combining “high performance” and luxurious “hand crafted interiors”, based on “trimmed with the finest supple leather, hand-finished wood veneers, gleaming metals and deep-pile carpets” (Bentley Motors, 2018). Current models include the luxury saloon car ‘Mulsanne’, the luxury sedan ’Flying Spur’, the grand tour car ‘Continental GT’ and the sports utility vehicle (SUV) ‘Bentayga’.

In the research ‘Continental GT’ is selected as the car to apply front-seat passenger infotainment solutions. Being a grand-tourer car with a high performance, Continental GT is promoted with delivery of ‘a true journey of discovery for the driver’ (Bentley Motors, 2018). It is a fact that there is not enough emphasis on the front-seat passenger who accompanies the driver as the second car occupant in this coupe type of car. Although, the very latest Continental GT series (launched in August 2017) allows the front-seat passenger to divide the screen into two for different functionalities and control the infotainment system simultaneously from the central console, the interactions and functionalities are still designed within the limitations of driving activity. Therefore, the motivation of empowering the front-seat passenger with infotainment systems becomes more relevant in such luxury grand tourer travel scenario where the expectation from a luxury automotive brand is to deliver luxury experience to both/all car occupants.

In addition to its contribution as defined within the scope of the research, the role of Bentley Motors in the research can be listed as: the professional feedback by the Bentley Motors HMI design team on the PhD progress and design & simulation proposals, provision of reference documents to be utilized in design and simulation development process (e.g. customer personas, GUI image data, 3D data of the car), and the researcher’s access to the Bentley Motors facilities for exploration of the Bentley Continental GT interior and interfaces.

Virtual Engineering Centre (VEC): The second research partner of the research is the VEC. The VEC was founded as a collaboration between the University of Liverpool (UoL) and the Hartree Centre to deliver “advanced modelling, simulation and visualisation” solutions to industry by integrating “academic research and latest scientific and technology infrastructure”. It is located both at the Sci-Tech Daresbury Laboratory and the VEC laboratory within the School of Engineering at UoL (VEC, 2018). The centre has several experiences in product development processes in automotive sector with luxury car brands including Bentley Motors, Jaguar Land Rover and Aston Martin.

The collaboration with the VEC includes: professional support whilst deciding the type of simulation technologies to be used in experience prototyping, development of the virtual reality simulation with available equipment, and visualisation and programming support (at various levels, further explained in 4.4. Design Detailing and Simulation Development). The VEC also provided its facilities and personnel to support the conduct of the user studies at the VEC-Daresbury Laboratory.

Regarding the impact of the research to the research partners; the contribution of the research to the VEC is expanding the capabilities of the centre in product development projects by providing a new vision in use of their simulation facilities (namely experience prototyping). The research also empowers Bentley Motors in its global competition with other luxury automotive brands in terms of design (potential to create unique selling points through interpretation of the results of the experience prototyping of the front-seat passenger infotainment system proposal) and design evaluation processes (appraisal of automotive HMI with VR simulation).

1.6 Breakdown of the Chapters

Chapter 1. Introduction first identified the problem areas that create the motivation to conduct the PhD research. They can be summarised as the need of i) infotainment solutions that provide front-seat passenger-oriented interactions and functionalities, which go beyond the traditional infotainment systems that are designed within the limitations/complexity of the driving activity, ii) investigation of simulation as a means of experience prototyping of these unprecedented front-seat passenger infotainment system solutions, and iii) investigation of the concept of luxury with regards to infotainment system experience. Based on the problem definition, it then introduced the aim, objectives, and research questions of the research together with the list of PhD studies and phases where each research question is answered. It also gave the details of collaboration with research partners and the role of each party (including the author) in achievement of the research aim and objectives.

Chapter 2. Literature Review presents the theoretical framework and the review of the technologies that are referred and further explored in design and simulation of the front-seat passenger infotainment system. It has four main sections:

2.2. Dimensions of user experience and user-product interactions first introduces the framework of *why, what* and *how* levels of interacting with technology (Hassenzahl, 2010). If the front-seat passenger infotainment system is handled as a form of technology; the *why* level refers to what front-seat passengers feel and think about the system, the *what* level refers to what they do / what information they deal with through the system, and the *how* level refers to how they interact with the system. The same section then deconstructs each level as qualities of a pleasant user experience (e.g. pragmatic and hedonic qualities), functionalities & content, and aspects of aesthetics of interaction (e.g. spatio-temporal aspects, visual aspects). This enables us to specify the dimensions of the front-seat passenger system and to discuss their specific contributions to the delivery of a pleasant user experience.

2.3. Concept of luxury and luxury values involves the review of marketing literature that explores the values expected to be delivered via luxury products-systems-services. The same section also presents a discussion of these luxury values in relation to the qualities of experience.

This section of the thesis (2.3) was presented as a conference paper "Product Experience and Luxury Values" (Yardım Sener et al., 2016) at the 10th International Conference on Design and Emotion held between 27th and 30th of September 2016 in Amsterdam, The Netherlands. The sections 2.3.1, 2.3.2 and 2.3.3. include passages that are quoted verbatim from the co-authored conference proceeding (ibid.) to which the author of this thesis contributed by her literature review on the luxury values.

With the section ***2.4. Contemporary automotive infotainment solutions to empower front-seat passengers***, the chapter shifts its focus from theory to practice, and presents the synthesis of (front-seat) passenger oriented UX studies and the technology review of a selection of concept cars. The section reveals diverse approaches followed in empowering front-seat passengers. It presents new control and display configurations, interaction technologies, trends followed in application of these technologies as well as a list of new functionalities (infotainment features) envisioned for the future infotainment systems.

This section was presented as conference paper-proceeding (Sen et al., 2018) with the same title at DRS (Design Research Society) Conference held between the 25th and 28th of June 2018 in Limerick, Ireland. All sub-sections of this part include passages that are quoted verbatim with further additions from the literature.

2.5. Experience prototyping with VR Simulation introduces the term prototyping, types of prototypes, and dimensions of prototyping decisions (e.g. medium). The section continues with introduction of virtual reality by mentioning its place within the 'reality-virtuality continuum' (levels of mixed reality: AR, VR) and its key aspects (e.g. immersion, presence). Since the simulation medium that will be used in prototyping is decided after the concept development of the infotainment system this section demonstrates both VR and AR simulation technologies. It finally touches upon the use of VR-AR in design research and user studies (including the automotive HMI appraisals) and discusses its advantages (e.g. safety) and disadvantages (e.g. simulator sickness).

Chapter 3. Methodology gives the details of the 'research through design' approach, briefly introduces each phase of the PhD research and discusses the contribution of each research phase to the others. This chapter presents an overview of the methods utilized in the research; however, the methodological details (e.g. study protocols, participant sampling) are further explained in the sections dedicated to each phase in Chapter 4.

Chapter 4. Design and Simulation of the Front-Seat Passenger Infotainment System compiles all practice-based phases of the PhD research, which contributes to design and simulation of the front-seat passenger infotainment system. They include either studies with research participants or the stages where the author develops the front-seat passenger infotainment system proposal and the VR simulation in collaboration with the Bentley Motors and the VEC.

The first phase of the design and simulation is presented in **Section *4.2. Focus group: Exploration of simulation challenges of Interaction Technologies (with the VEC),*** which is conducted to shortlist a selection of interaction technologies that literature review introduces, so that the selected ones can be further considered for the infotainment system design and its simulation. The shortlisting process includes the discussion of how challenging it would be to communicate interaction aesthetics offered by each technology with VR and the simulation technologies that would work best to prototype an infotainment system which integrates that specific interaction technology.

4.3. Concept Development of the front-seat passenger infotainment system is about the stage where author creates a travel scenario with a series of functionalities (infotainment features). The concept development phase also includes design proposals for the control and display alternatives that are based on the interaction technologies shortlisted in the focus group. The section concludes with a discussion of the functionalities and control & display alternatives regarding their suitability for Bentley Continental GT experience.

4.4. Design detailing and simulation development first introduces the final infotainment system proposal, which involves the spatial configuration of the infotainment control and displays, main principles of infotainment interactions (e.g. gestures), and the travel scenario which introduces all the infotainment features and the relevant interaction tasks in detail. Having presented the final design proposal, the section continues with the details of the simulation development. It first presents how decisions regarding what to prototype; scope, fidelity and medium of the prototype are taken; then explains the visualisation and programming processes that are supported by the VEC.

Chapter 5. Experience Prototyping of the Front-Seat Passenger Infotainment System through VR Simulation gives answers to all UX-related research questions.

5.2 Methodology introduces the study set-up and details such as the venue, participants (sampling/exclusion criteria and recruitment) and the study protocol. This information is followed by the demonstration of all the research materials used in data collection, including simulation setting & equipment; simulation evaluation materials and user experience evaluation materials that are utilized before/during/after the VR demonstration of the travel scenario which contains the final front-seat passenger infotainment system proposal.

5.3 Analysis Overview demonstrates the overview of methods and tools used in data analysis.

5.4. Evaluation of the simulation presents the results of the statistical analysis of the simulation sickness and presence questionnaires.

5.5. Evaluation of the User Experience of the Front-Seat Passenger Infotainment System first presents the results of the UX evaluation questionnaire which is a Likert scale with semantic differential pairs that refer to diverse qualities of luxury experience. It then shares the results of the content analysis of the follow-up interview, which constitutes the main contribution of the study.

The chapter ends with a discussion of the results and presents the key points to consider in design and development of future front-seat passenger infotainment systems.

Chapter 6. Conclusions presents the summary of the phases of the PhD research, revisits the research questions, discusses the contributions of the research to knowledge. It synthesizes the answers given to the research questions by providing concise recommendations for luxury front-seat passenger infotainment system design and VR prototyping of the car-HMI. It also discusses the limitations and implications of the research and concludes with further research directions and opportunities.

CHAPTER 2.
LITERATURE REVIEW

2.1 Introduction

The PhD research investigates the experience dimensions of the luxury infotainment system that will empower front-seat passengers. In other words, it articulates how our design decisions regarding the interaction aesthetics and functionalities of the infotainment system deliver hedonic or pragmatic qualities within front-seat passenger's travelling experience in a luxury car. Achievement of this research aim is possible through i) design and development of a front-seat passenger infotainment system based on the investigation of promising interactions and functionalities; ii) communication of the design proposal with the appropriate prototyping tools and simulation technologies, and; iii) execution of the user studies to investigate the user experience of the design proposal through prototyping.

This literature review covers the key concepts and practices referred in this PhD study to achieve the above-listed aim and objectives. It first elaborates on the 'Dimensions of User Experience and User-Product Interactions' to deconstruct the user experience and user-product interactions into a variety of qualities/aspects/dimensions, so that we can explore the relationship among them in design and prototyping phases of the PhD study. As mentioned in the Introduction chapter, the PhD research is conducted in collaboration with the UK-based luxury car manufacturer – Bentley Motors, and Bentley Continental GT model is selected as a luxury car context to study the concept of front-seat passenger infotainment system. Therefore, the second section of the literature review is devoted to 'The Concept of Luxury and Luxury Values' to enable the discussion of the expectations from the user experience of the front-seat passenger infotainment system in a *luxury* car. This section introduces the concept of luxury, identifies 'luxury values' and discusses these values in relation to the qualities of user experience that are introduced in the first section of the literature review. The following section is 'Contemporary automotive infotainment solutions to empower front-seat passengers', which constitutes the key reference for the investigation of new interactions and functionalities ('infotainment features') for the front-seat passenger infotainment system. This section provides a comprehensive review and a structured analysis of the academic and industrial efforts regarding improvement of the front-seat passenger experience. It presents technology trends in automotive user interface design through the review of concept cars introduced in several international automotive and technology shows. The last section before the conclusions of the literature review is 'Experience prototyping with virtual reality simulation'. It presents the concepts of prototype and prototyping, virtual reality simulation, key aspects of VR simulation (e.g. presence) and simulation technologies. Since this PhD study utilizes VR to gather data about user experience of the front-seat passenger-oriented automotive user interfaces, this section also discusses the use of virtual reality (VR) as part of prototyping in industrial and automotive design.

2.2 Dimensions of User Experience and User-Product Interactions

2.2.1 *Why, What* and *How* Levels of Interacting with Technology

This section will introduce the *why, what* and *how* levels of interacting with technology (Hassenzahl, 2010) as the very basic framework to explain the user experience of front-seat passenger infotainment systems.

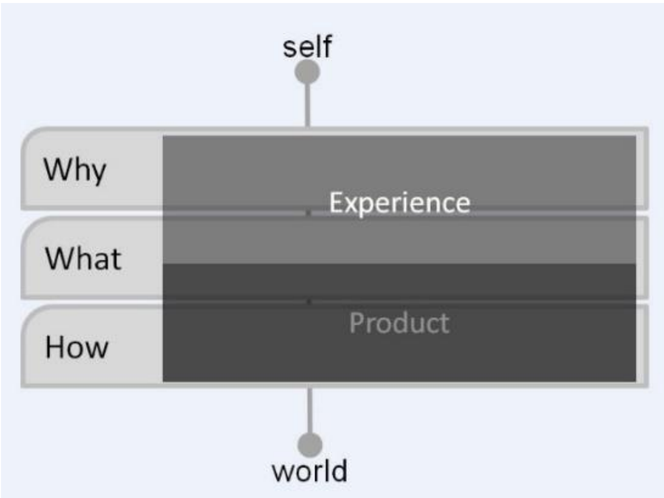


Figure 2.1 *Why, what* and *how* levels of interacting with technology (Hassenzahl, 2010)

The framework of the levels of interacting with technology (Figure 2.1) is presented by Hassenzahl (2010) with reference to the activity theories in psychology. It investigates how user connects his/her *self* to the *world* through an activity with/through a three-level goal hiearchy. It presents *what* level for 'do-goals', which refers to the tasks to be completed or a concerete goal to be achieved by users such as making a phone call. At the lowest, there is *how* level for 'motor-goals', which involves all the operational steps and interactions that users go through while dealing with the product. In phone-call example, it refers to grabbing the phone, browsing the contact list, selection of the contact, tapping on the phone icon etc. However, beyond these instrumental interactions, at the highest level, there is *why* level for ‘be-goals’ which is about meaning, motivations and emotions related to that activity. By making a phone-call we feel related to other people (See Figure 2.2).

As can be seen in Figure 2.1, from *how* to *why*, the focus shifts from the product/technology itself to the experience of the product/technology. The three levels presented in the framework enable us to differentiate the user-product interactions from the user experience resulting from user-product interactions. This research deals with the front-seat passenger infotainment both as a product and an experience. In this regard, the *why* level refers to all the emotions and meanings associated with the use of the front-seat passenger infotainment system such as the relatedness to the Bentley users' network, or the feeling of discovery. *What* level refers to all the functionalities/infotainment features provided to front-seat passengers of Bentley Continental GT, such as event suggestions. *How* level is about how the front-seat passengers will interact with the infotainment system; e.g. if the event suggestions will be provided as pop-up notifications or in more sequential way; or the level of detail of the event information will be presented.

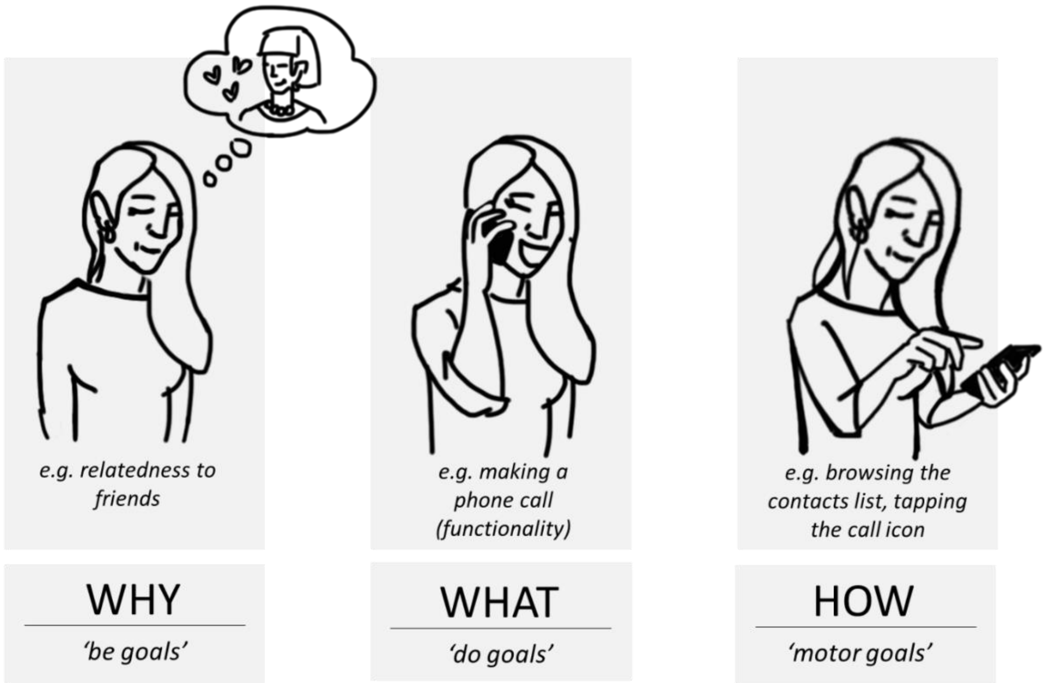


Figure 2.2 *Why, what* and *how* levels of interacting with a phone (Adapted from Hassenzahl (2010), illustrated by the author)

Investigation of the front-seat passenger infotainment system interactions and experience requires reference to the qualities of the *how* and *why* level. Therefore, this literature review builds on a synthesis of the research that identifies the varied dimensions/ qualities/aspects/attributes of user experience and interaction. Identification of these qualities is significant for both design and prototyping phases of this PhD research. While aspects of interaction (e.g. spatial aspects like movement range of hand gestures) help us to deconstruct the design decisions and to filter the prototyping options; the qualities of the user experience help us to discuss what would make the experience of the front-seat passenger infotainment system e.g. efficient, captivating or presentable. Since this study handles the front-seat passenger infotainment system in a luxury car context, this literature review will also touch upon the concept of luxury and luxury values with regards to the qualities of user experience.

2.2.2 Deconstructing the HOW: The Aspects of (Aesthetics of) Interaction

The term aesthetics of interaction emerged from the need to explain the appreciation of our sensory experience of the products, which goes beyond the appreciation of the visual appearance. In other words, it is used to define/design products, which are not only pleasant to look at, but also pleasant to use (Djajadiningrat et al., 2004). In their product experience framework Desmet and Hekkert (2007) differentiate the aesthetic experience from the experience of meaning and the emotional experience. However, in some sources (Wright et al., 2008; Petersen et al., 2004) the term aesthetics of interaction or aesthetic experience is used to refer not only to the way we interact with products via different sensory modalities (*how*), but also to our emotional and intellectual reflections on the product interactions (*why*). This section deals with aesthetics of interaction only through the deconstruction of the *how*. It identifies the aspects of the interaction rather than dealing with what makes the interaction/experience an aesthetic one.

Aesthetics of interaction in product design literature is discussed through the sensory aspects of the products (Desmet & Hekkert, 2007, Locher et al., 2010). It is a fact that we interact with most of the product aspects through our sensory system, however we need to acknowledge certain characteristics of interaction (e.g. sequence of interaction steps, range of movement, precision in information presentation) separately to deal with the complexity of interactive systems. Such motivation has been explained as “suggesting an interaction vocabulary” (Diefenbach, 2013) or “creating a language to describe interactivity regardless of its physically or visually manifested forms” (Lim et al., 2009).

All products can be considered as interfaces and they have diverse levels of interactivity. In fact, the possibilities for interactivity increase with the embodiment of computing technologies. Similarly, the extent of information the users deal with also varies depending on the type of interface e.g. a graphical user interface vs. a physical artefact. This PhD investigates the front-seat passengers' in-car interactions within the scope of the infotainment system. Therefore, the research deals with the car not only as a product or as a space (interior design); but also, as a complex interactive system for the front-seat passenger. This requires a comprehensive 'vocabulary' that will be used to explain the interactivity of the front-seat passenger infotainment system.

Lenz et al. (2014) presents a literature synthesis of the academic research that defines the aspects of aesthetics of interactions. The terminology used in such research varies as "interaction-related properties" (Lundgren, 2011), "interaction vocabulary" (Diefenbach et.al, 2013), interactivity attributes (Lim et al., 2009), "attributes of interaction gestalt" (Lim et al., 2007) and "interaction design dimensions" (Hallnäs, 2011).

Diefenbach et al. (2013) and Lenz et al. (2014) point out that most of these studies oversee the conceptual difference between the experience (why) and interaction (how) related qualities. They give example from Lim et al. (2009), who present both a quality of experience like "expectedness" and a physical interaction attribute like "movement range"' together under interactivity attributes. Hence, while presenting their literature synthesis about aesthetics of interaction, Lenz et al. (2014) first cluster the collected aspects as "be-level attributes" (experience-related) and "motor-level attributes" (interaction-related). As mentioned earlier, this section is dealing with the aspects of the interaction rather than what makes the interaction an aesthetic one. Therefore, it will now refer only to the taxonomy of "motor-level attributes". The categories under this taxonomy include "temporal", "spatial", "action-reaction", "presentation", "forces" and "meta" (Lenz et al., 2014). Table 2.1 presents the explanation of these categories with examples.

Table 2.1 Motor-level attributes of interaction (Adapted from Lenz et al., 2014)

Temporal	duration of interaction, sequence of interaction steps	e.g. rhythm
Spatial	use of space, spatial distribution of elements, direction of interaction	e.g. movement range
Action-Reaction	relation of action and reaction, feedback, response	e.g. mediated vs. direct (the switch on / next to the lamp)
Presentation	way of presenting information and interaction possibilities	e.g. approximate vs. precise (numeric vs. graphic representation)
Forces	force necessary to interact, application of force that characterizes the interaction	e.g. interaction effort
Meta	context of interaction, participants, connections, input/output modalities	e.g. body parts involved

Lenz et al. (2014) underline the fact that these categories are self-constructed, and we may not rely on the theoretical derivation of these facets. It is indeed possible to find some overlapping interaction aspects among these categories. For example, if there is a movement in interaction, it means that there is a change in the spatial status of interactive items in time. Therefore, the movement can be explained with both spatial and temporal aspects. Another example is that the "response time" is considered as an "action-reaction" aspect by Lenz et al. (2014), since it defines how the product reacts to the user's input; however, it also implies temporality. Similarly, spatial decisions such as position of a lamp switch in relation to the lamp itself can change the characteristics of an interaction in terms of its 'action-reaction' related aspects (e.g. mediated vs. direct).

Another reason why these categories may not be completely reliable is that there is no direct reference to sensory aspects of the products, although these attributes are presented as part of aesthetics of interaction. This is not surprising, since some of these attributes are collected from the research that aims to establish "a language to describe interactivity regardless of its physically or visually manifested forms" (Lim et al., 2009). For example, the texture of a physical control may not be considered as an "interactivity attribute" as itself, yet the texture of the physical control starts to matter in terms of aesthetics of interaction, as users start to interact with that physical control and associate a specific texture with a specific quality of experience such as stimulation. In conclusion, we need a vocabulary that will also include the 'sensory-specific' aspects of interaction in addition to the motor-level attributes categorized in Table 2.1. Some categories presented in Table 2.1 such as "forces" and "spatial aspects" resonate with the sensory modality of kinesthetics, while other categories can include any sensory interaction. We need a separate category for 'sensory-specific' aspects of interaction like colour (visual aspects) or texture (tactile aspects) that become part of interactivity with user's involvement.

The categories in Table 2.1 overlap with some of the categories and terminology used in other models or frameworks of user-product interactions and user experience. Now, these frameworks will be introduced, and the above-mentioned motor-level attributes will be discussed in relation to these frameworks. Then, the different approaches will be synthesized in a diagram, which will be followed by distribution of the corresponding aspects of interaction under relevant categories.

Figure 2.3 shows the model of human-product interaction presented by Hekkert & Schifferstein (2008) who deconstruct the product properties as "sensory properties", "possibilities for behaviour", and "functionality".

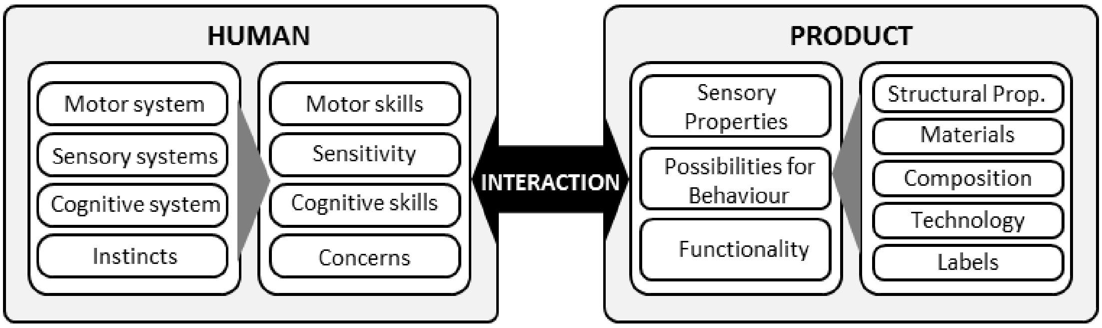


Figure 2.3 Model of human-product interaction (Adapted from Hekkert & Schifferstein, 2008)

On the other hand, in his user experience model, Hassenzahl (2003) lists the product features as "content", "presentation", "functionality" and "interaction" (Figure 2.4). There is no clear definition of the term content in the paper, however we can clarify the term with an e-book reader example e.g. Kindle. If the *functionality* of a Kindle device is to read e-books, the *content* is expected to be the e-books and any other information provided within the device. If these two frameworks are compared, it can be claimed that the terms *presentation* and *interaction* (Hassenzahl, 2003) correspond to the term *possibilities for behaviour* (Hekkert & Schifferstein, 2008). There is no direct reference to the *sensory properties* of a product in the user experience model of Hassenzahl.

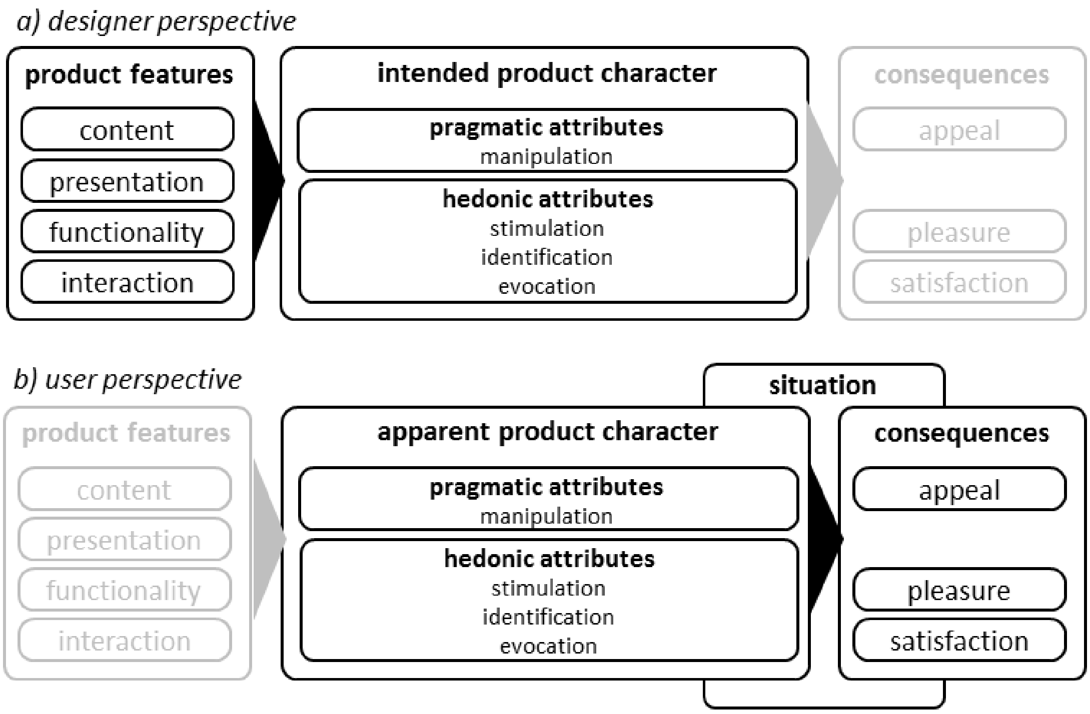


Figure 2.4 Hassenzahl's user experience model (2003)

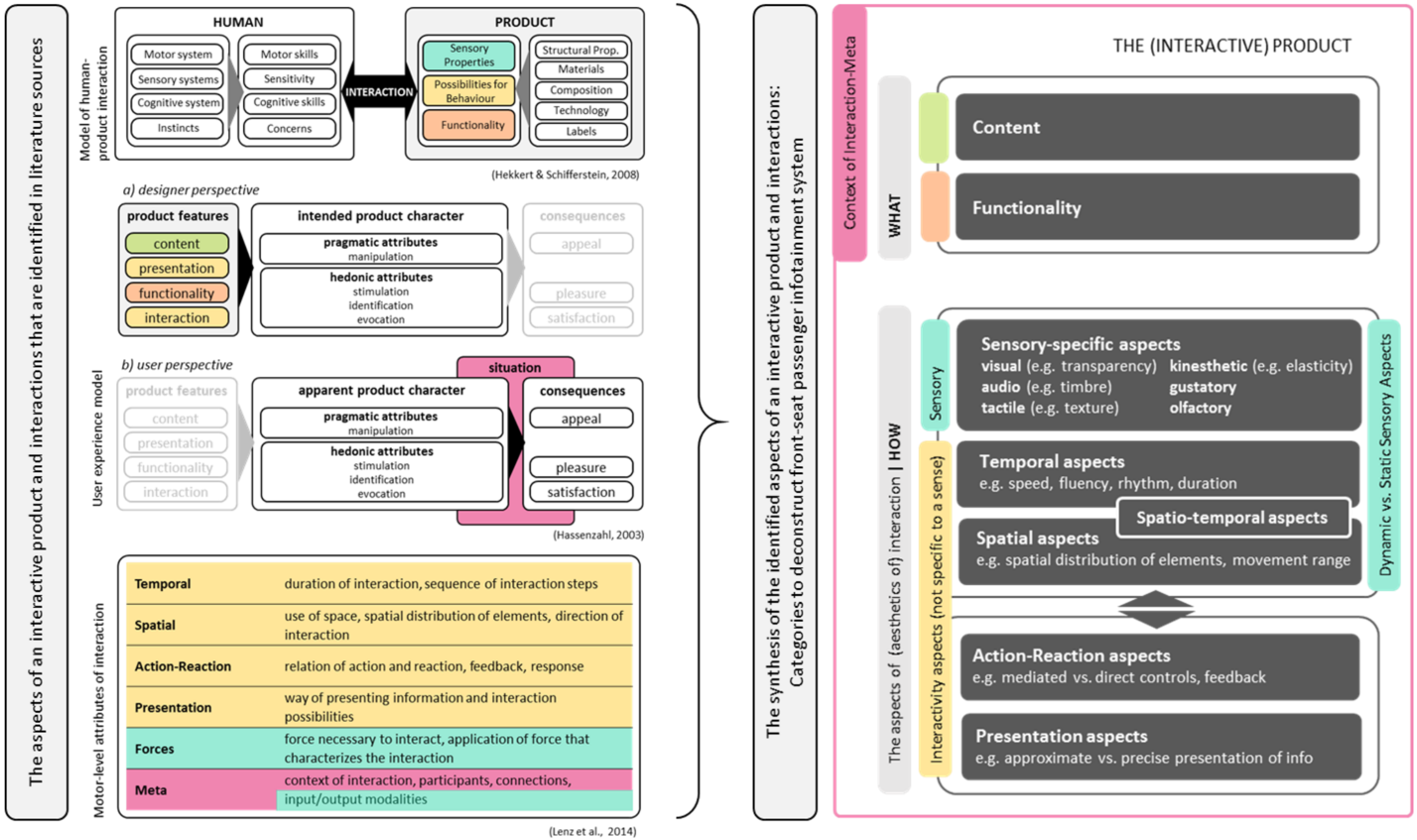


Figure 2.5 The synthesis diagram to conceptualise the varied aspects of an interactive product

So, where do these motor-level attributes (Lenz et al.,2014) presented in Table 2.1 fit within these frameworks? The answer of this question can be found in the diagram presented in Figure 2.5, which synthesizes the similar terms under specific colour-coded categories and show the relations among them:

As mentioned earlier, the *what* and *how* levels of interacting with technology are more related with the product aspects, whereas the *why* level is more about the experience of these product aspects (See Figure 2.1). The literature synthesis diagram in Figure 2.5 presents the varied aspects of an interactive product, therefore the scope is the *what* and *how* levels.

The term *functionality* is used by both Hassenzahl (2003) and (Hekkert & Schifferstein, 2008) as a product property or feature**.** In the diagram (Figure 2.5), **the functionality and the content** are categorized under **the *what* level**. They both imply *what* users do by interacting with the product or *what* the users interact with, rather than how they interact with the product.

The *how l*evel aspects are grouped as **the sensory-specific aspects** and the **interactivity aspects that are not specific to a sensory modality.** The *temporal*, *spatial*, *action-reaction* and *presentation* attributes are *the interactivity aspects that are not specific to a sensory modality.* For example, *rhythm* is a temporal aspect of interaction and we can talk about the rhythm of an audio, visual or a tactile feedback. To explain this phenomenon Camere et al. (2015) use the term “dynamic sensory properties”, when spatio-temporal attributes are communicated through a specific sensory channel (e.g. visual changes, vibration feedback). However, being static or dynamic, *sensory properties* are not enough to cover other motor-level attributes of interaction (Lenz et al., 2014) like *action-reaction* and *presentation* aspects.

There is a cause-effect relationship among the two group of interaction aspects as can be seen in the diagram (see Figure 2.5). *Presentation* and *action-reaction* aspects of interaction are based on the decisions regarding *sensory-specific*, *spatial* and *temporal* aspects of interaction and *vice versa*. For example, providing information to the users in either approximate or precise way is a decision about the *presentation* aspect of the interaction. In a medical device for the diabetics, the blood sugar levels can be shown with digits by providing the precise data; or high vs. low blood sugar levels can be communicated through colour-coding in an approximate way, which means that the execution of this presentation-related decision is based on the design decisions about *visual (sensory-specific)* aspects.

Another motor-level attribute, the **forces** category, is defined as "force necessary to interact, application of force that characterizes the interaction" (Lenz et al., 2014). If it implies the physical effort, the force related aspects can be considered as sensory aspects, more specifically the *kinesthetic aspects.* That's why *the forces* is not shown as a separate category but as part of sensory specific aspects.

The final motor level attribute, the **meta** category refers to the context of interaction, which may correspond to *the situation* in Hassenzahl's (2003) user experience model. In the synthesis diagram (Figure 2.5) the *context/meta* is visualized in a way that it refers to the context of use affecting the product interactions and the functionality (e.g. a road trip with a car in an unfamiliar region). However, it can still be considered as a decision item while designing interactions; such as the connectivity of the car infotainment system with the infrastructure. In this regard, it is still an aspect of the interactive product, as it is a matter of embodiment of the necessary technologies that will enable the car to offer more context-aware and networked interactions.

Table 2.2 is the distribution of the aspects of interaction under the categories presented in Figure 2.5. The distribution is based on the literature synthesis and the categorization presented by Lenz et al. (2014). This table additionally presents a cluster of the interaction aspects with similar meanings in each bullet-point.

Table 2.2 The aspects of interaction

The aspects of (aesthetics of) interaction |HOW	Sensory-specific aspects	**Visual aspects**	colour, configuration, form (3D), geometry, graphic, illumination, layout, pattern, position, proportion, reflectivity, shape (2D), size, transparency **[12]**
		Tactile aspects	chili heat, friction, hardness, oiliness, stickiness, temperature, texture, wetness **[12]**
		Kinesthetic aspects	elasticity, inertia, momentum, movement, plasticity, position, rigidity, weight **[12]**
		Audio aspects	loudness (volume), pitch (frequency), timbre **[12]**
		Smell aspects	fragrance, notes, stink, volatility **[12]**
		Taste aspects	acid, bitter, metallic, salty, savoury, sour, sweet **[12]**
	Interactivity aspects that are not specific to a sensory modality	**Temporal Aspects**	• fast-slow **[2]**; speed, pace **[6]**; movement speed **[5]** • stepwise-fluent **[2]**; continuity (continuous vs. discrete) **[5]**; interaction flow (concrete vs. discrete) **[8]** • concurrency (concurrent vs. sequential) **[5]**; time-depth (concurrent vs. sequential) **[6]** tasking **[8]** • timing **[4]**; live time, real time, unbroken time, sequential time, fragmented time, juxtaposed time **[9]** • constant vs. inconstant **[2]** • rhythm **[7]** • duration **[11]**
		Spatial Aspects	• spatial separation-spatial proximity **[2]**; jumping, breathing, expanding **[1]** • movement range (narrow vs. wide range) **[5];** size **[11]** spacing **[4]**; • locality (co-located vs. distant) **[8]** • movement (modest vs. dynamic) **[8]** • body attitude **[10]** • shape qualities (change in shape) **[10]** • reach **[10]** • orientation **[11]** • position **[11]**
		Action-Reaction Aspects	• instant-delayed **[2]**, response time **[8]**, response speed (prompt vs. delayed) **[5]** • apparent-covered **[2]** • mediated-direct **[2]**; pliability **[7]**; directness (direct vs. indirect manipulation) **[8]** • freedom of interaction (The no of ways to achieve the same outcome: free vs. forced) **[3][8]** • incidental-targeted **[2]** • uniform-diverging **[2]** • adaptability (the ability to adapt user's habits and actions: forgetting vs. accommodating) **[8]** • robustness (robust vs. fragile) **[8]** • dependency (automatic vs. dependent) **[8]** • initiative **[10]** • sequence (singular vs. plural input) **[11]** • presence **[11]**
		Presentation Aspects	• approximate-precise **[2]**; proximity (precise vs. proximate) **[5] [6]**; precision (precise vs. proximate) **[8]** • resolution (dense vs. scarce) **[6]**; presentation (the richness of the presented info: detailed vs. scarce) **[8]** • orderliness (random vs. orderly) **[6]**; information order (linear vs. scattered) **[8]** • clarity (how clear the product's output or appearance is) **[9]**

[1] Alaoui et. al (2011), **[2]** Diefenbach et al. (2013), **[3]** Djajadiningrat et al. (2004), **[4]** Hallnäs (2011), **[5]** Lim et al. (2009), **[6]** Lim et al. (2007), **[7]** Löwgren (2009), **[8]** Lundgren (2011), **[9]** Lundgren (2009), **[10]** Ross & Wensveen (2010), **[11]** Saffer (2009) **[12]** Sener & Pedgley (2014).

2.2.3 Deconstructing the WHAT

Synthesis of the literature on the aspects of aesthetics of interaction (*how* level) is presented under the aspects of an interactive product. Therefore, the previous section already touched upon the components of the *what* level as part of the interactive product and they are identified as i) 'functionality' and ii) 'content', which refer to i) what users do by interacting with the product and ii) what information they are interacting with. Within the scope of the front-seat passenger infotainment, the functionalities offered by the system will be referred as infotainment features. Deconstruction of the concepts of functionality and content only makes sense, when we know 'what' interactive product we are examining. Section 2.4 'Contemporary Automotive Infotainment Solutions to Empower Front-Seat Passengers' presents a categorization of the infotainment features identified in passenger-oriented academic research and in a selection of concept cars.

2.2.4 Deconstructing the WHY: The Qualities of User Experience

The previous section presented the varied aspects of user-product interaction so that the design decisions regarding the front-seat passenger infotainment system can be deconstructed. This way we can identify exactly which aspect of the interactive system plays role in delivering a specific quality in user experience. The deconstruction was also significant to understand which aspect of the interactive system can be communicated or not with a specific prototyping tool. This enables us to limit the scope of the analysis of the experience prototyping.

This research requires another set of aspects to deconstruct the why level - to identify the qualities of user experience. These qualities constitute the metrics for users; in this research, participants of the experience prototyping, to evaluate the user experience of the front-seat passenger infotainment system.

Here the term "quality" is not only used as an alternative to the terms 'dimension' or 'aspect', it also refers to the quality or the value delivered via user experience. Handling the front-seat passenger infotainment system within the scope of the luxury car necessitates discussion of the qualities of user experience in relation to the concept of luxury. Hence, the concept of luxury and luxury values will also be touched upon in the following section of the literature review.

In this section user experience model of Hassenzahl (2003) is again referred to deconstruct the *why* level. The model explains user experience through product characters/qualities (both terms are used by the author in varied papers) and divides them into two as pragmatic characters and hedonic characters (Figure 2.4). While the pragmatic characters are related with the usefulness and usability of the product; hedonic qualities are defined as "stimulation" (providing new impressions, opportunities, and insights), "identification" (communicating an identity) and "evocation" (provoking memories). Within this cause and effect relationship, Hassenzahl includes "situation" as a factor which influences user's interpretation of the intended pragmatic and hedonic product characters. As a "consequence" of these interpretations, in other words, when these characters become apparent, the product appeals to user, or contributes to the pleasure and satisfaction of the user.

Hassenzahl (2010) discusses that the pragmatic quality connects primarily with the *what* and *how* levels of interacting with technology, while the hedonic quality connects primarily with the *why* level. It is already argued that *what* and *how* levels are about do-goals. In this context pragmatic quality is about achievement of do-goals, whereas hedonic quality focuses on the self and be-goals. Pragmatic quality is included in this section as a dimension of user experience (*why*); since it is not about the functionality of the product itself, but the satisfactory delivery of the functionality of the product.

When the academic studies on 'the metrics of user experience' or 'quantifying user experience' are scanned (Sauro & Lewis, 2016), it is observed that these studies usually define metrics for the pragmatic qualities, and measure how useful and usable the products are. The number of user experience methods or scales that also define metrics for the hedonic qualities of the user experience is limited. Therefore, this section will touch upon the studies that answer the question of "What are the characteristics of a high quality, pleasant or luxury user experience?" not only through pragmatic but also hedonic qualities.

To answer this question, this section will first refer to the studies that identify the main psychological needs (Sheldon et al., 2001), product pleasures (Jordan, 2000; Tiger, 1992) and the pragmatic-hedonic qualities of experience (Hassenzahl, 2003). Then, it will refer to the luxury values (Reddy & Terblanche, 2005; Berthon et al., 2009; Kapferer and Bastien, 2009; Wiedmann et al., 2013) presented mainly in marketing literature, and discuss how these approaches relate to each other and identify similar or common qualities of user experience.

Hassenzahl and his colleagues (2010) discuss how the pragmatic or hedonic qualities of experience are linked with need fulfilment and demonstrate the connections among the pragmatic or hedonic qualities, the psychological needs and the (product) pleasures as can be seen in Table 3. The AttrakDiff Questionnaire (Hassenzahl et al., 2003), is also added to the references in this adapted version of the table. This questionnaire includes semantic differential keywords that describe the pragmatic quality (manipulation) and hedonic quality (identification and stimulation). Granted that it was originally introduced in German, Hassenzahl et al. (2015) was referred for the updated and English version of the questionnaire.

Table 2.3 Hedonic - Pragmatic Qualities of UX vs. Ten Human Needs and Four Pleasures in product (Adapted from Hassenzahl et. al, 2010).

Hedonic - pragmatic qualities of UX (Hassenzahl 2003)	**AttrakDiff2 Questionnaire** (Hassenzahl et.al, 2003; Hassenzahl et.al, 2015)	**Ten human needs** (Sheldon et al., 2001)	**The four pleasures** (Jordan, 2000)
		Autonomy - independence Feeling like you are the cause of your own actions rather than feeling that external forces or pressure are the cause of your action	
Manipulation **(Pragmatic Quality - PQ)** Utility and usability	Technical—human Complicated—simple Impractical—practical Cumbersome—straightforward Unpredictable—predictable Confusing—clearly structured Unruly—manageable	**Competence - effectance** Feeling that you are very capable and effective in your actions rather than feeling incompetent or ineffective **Security - control** Feeling safe and in control of your life rather than feeling uncertain and threatened by your circumstances	**Psycho-pleasure**
	Isolating—connective Alienating—integrating Separates me—brings me closer to people	**Relatedness - belongingness** Feeling that you have regular intimate contact with people who care about you rather than feeling lonely and uncared of	**Socio-pleasure**
Identification **(Hedonic Quality - HQ-I)** Communicating an identity	Unprofessional—professional Tacky— stylish Cheap—premium Unpresentable—presentable	**Influence - popularity** Feeling that you are liked, respected, and have influence over others rather than feeling like a person whose advice or opinion nobody is interested in	
Stimulation **(Hedonic Quality - HQ-S)** Providing new impressions, opportunities, and insights	Conventional—inventive Unimaginative—creative Cautious—bold Conservative—innovative Dull—captivating Undemanding—challenging Ordinary—novel	**Pleasure - stimulation** Feeling that you get plenty of enjoyment and pleasure rather than feeling bored and understimulated by life	**Psycho-pleasure**
		Physical thriving Feeling that your body is healthy and well-taken care of rather than feeling out of shape and unhealthy	**Physio-pleasure**
Evocation **(Hedonic Quality)** Provoking memories		**Self-actualizing - meaning** Feeling that you are developing your best potentials and making life meaningful rather than feeling stagnant and that life does not have much meaning	**Ideo-pleasure**
		Self-esteem - self-respect Feeling that you are a worthy person who is as good as anyone else rather than feeling like a ''loser''	
		Money - luxury Feeling that you have plenty of money to buy most of what you want rather than feeling like a poor person who has no nice possessions	

These qualities are first compared with the “Ten Human Needs”- the set of 10 psychological needs that are identified by Sheldon et al. (2001) with reference to a variety of psychological theories. *Competence, autonomy* and *relatedness* are driven from Deci and Ryan’s self-determination theory of motivation (1985). *Physical health, security, self-esteem, love-belongingness,* and *self-actualization* are driven from Maslow’s theory of personality (1954). The need for *pleasurable stimulation* is driven from Epstein's cognitive-experiential self-theory (1990). Sheldon et al. also add *popularity-influence* and *money-luxury* (Derber, 1979) to this list, although they acknowledge the fact that their contribution to happiness is controversial.

Another approach which is included in the comparison shown in Table 2.3 is the “the four pleasures” in product use by Jordan (2000). He deconstructs the pleasant user experience into *physio-pleasure, socio-pleasure, ideo-pleasure,* and *psycho-pleasure.* This classification of pleasures is first introduced by the anthropologist Tiger (1992) and adapted by Jordan to product design discipline. According to Jordan (2000), *physio-pleasure* is driven from different sensory interactions with the product, including its contribution the physical wellbeing, *socio-pleasure* is about the product’s role in the quality of social relationships, *pyscho-pleasure* is about the quality of the users’ cognitive and emotional relationships with the products, and *ideo-pleasure* is about the product’s appeal to people’s values. These pleasure types are also referred by Uotila et al. (2005) to define the characteristics of luxury products/experiences.

The hedonic quality as an umbrella term -regardless of its sub-categories which are stimulation, identification and evocation- can be mapped onto the all psychological needs defined by Sheldon et al. (2001) by its own definition. While deconstructing the *why* level, Hassenzahl (2010) and Lenz et al. (2014) select the most relevant seven needs in the context of interactive product experiences by excluding self-esteem (because it is seen a result of need fulfilment rather than the need itself), luxury (because of its specific role in Sheldon et al.’s study) and physical-thriving (based on its irrelevance to most of the interactive systems). Going back to the literature synthesis on the aesthetics of interaction; Lenz et al. (2014) presents the list of seven needs (autonomy, competence, relatedness, popularity, stimulation, security and meaning) as “be-level attributes” of interaction (the *why* level). However, there are specific needs which are expected to be fulfilled by the achievement of a task through utility and usability of a product. Therefore, as can be seen in Table 3, *pragmatic qualities (manipulation)* are matched with the need of competence by Hassenzahl (2010) and security-control by Lenz et al. (2014) as well as the psycho-pleasure.

From hedonic qualities, identification is associated with influence-popularity and socio-pleasure by Hassenzahl et al. (2010). Attrakdiff2 questionnaire items for the identification also involve semantic differentials such as alienating-integrating, isolating-connective or separates me from people-brings me closer to the people. Therefore, this hedonic quality is also linked with the need of relatedness in Table 3, unlike the original table presented by Hassenzahl et al. (ibid.).

Stimulation is matched with pleasure-stimulation and psycho-pleasure, since the term stimulation is taken as a cognitive and emotional aspect of experience rather than sensory one.

Finally, *evocation*, which is about product’s ability to provoke memories, is linked with the *self-actualizing/meaning* and *ideo-pleasure* by Hassenzahl and his colleagues (2010). Evocation is excluded from the Attrakdiff Questionnaire’s hedonic quality-related items, as evocation is not relevant, when the users evaluate a product that they have no past experiences with (Hassenzahl, 2004). Nevertheless, the creation and attribution of meaning does not necessarily require past experiences with the product. In fact, only if we expand the scope of the term evocation from provoking memories to any type of meaning creation and attribution, linking it with self-actualizing/meaning and ideo-pleasure makes sense.

From Table 2.3, we observe that there are few potential needs (e.g. autonomy, security) and pleasures (physio-pleasure) for the pragmatic and hedonic qualities to cover depending on the type of the product or the context of use. We also see that the concept of luxury is reduced to the ownership of expensive items. The following section entitled ‘The concept of Luxury and Luxury Values’ will present a broader perspective of luxury and luxury experience that resonates with the qualities of experience presented in this section.

2.3 The Concept of Luxury and Luxury Values

This section will present the concept of luxury, its positive and negative connotations, and the 'luxury values' to define the varied dimensions of the experience of luxury products. Then, it will provide a comparison of the experience qualities presented earlier with these luxury values-features. This section of the thesis had been presented as a conference paper 'Product Experience and Luxury Values" (Yardim Sener et al., 2016) at the 10th International Conference on Design and Emotion, held between 27th and 30th of September 2016 in Amsterdam, The Netherlands. The sections 2.3.1, 2.3.2 and 2.3.3. include passages that are quoted verbatim from the co-authored conference proceeding (ibid.) to which the author of this thesis contributed by her literature review on the luxury values.

2.3.1 The Concept of Luxury

The term luxury may imply a variety of meanings. Armitage and Roberts (2016, p.2) exemplify the typical connotations of the word luxury as:

> We can easily think of a luxury car, such as a Ferrari F12berlinetta; the luxury of flying in a private jet, such as a Gulfstream G650; a luxury celebrity wedding replete with every extravagance; or even a luxury dining experience involving Tasmanian leatherwood honey, Shanghai hairy crab, Caspian "000" beluga caviar, and other culinary frills.

The authors question if there is anything common in these examples to enable us to set a concrete definition of luxury which would make sense for any context. Then, they argue that it is not possible to set a meaning of the term only through objects, phenomena or acts without referring to the discursive context that defines the meaning of luxury by itself (ibid.). Mehta (2014) also mentions about luxury as a relative term. For example, a particular car might be luxury to some people, whilst ordinary to others. In this regard, Kapferer (2012) points out the relativity of luxury by using the definition "the ordinary of the extraordinary".

Etymologically, the word luxury is derived from the French term "luxurie", which means excess, lasciviousness, and negative self-indulgence". It can be further rooted back to the Latin word "luxus", which means "soft or extravagant living, sumptuousness, opulence" (Oxford Dictionaries of English, 2015). Therefore, the origins of the word luxury in Latin and Roman languages suggest not just indulgence but also *vicious* indulgence unlike the neutral meaning of the English *luxury* (Armitage & Roberts, 2016).

In the Oxford Dictionaries of English (2015) the contemporary definitions of luxury are provided as "a state of great comfort or elegance, especially when involving great expense";

“an inessential, desirable item which is expensive or difficult to obtain” and “a pleasure obtained only rarely”. Depending on the context, luxury has been associated with superior qualities of an object or service, high price, high-class, rarity/uniqueness of an item, pleasurable experience, as well as unnecessary consumption and extravagant life-styles. Associations with quality tend towards a positive meaning of luxury, whereas associations with opulence tend towards a negative meaning.

As luxury has strong connections with consumption, the positive and negative connotations of luxury have inevitably evolved with economic developments. The emergence of an industry or ‘market segment’ for luxury goods and luxury brands draws back to the nineteenth century’s Industrial Revolution and the establishment of companies seeking to produce exceptional products for the taste of the social elite at that time (Antoni et al., 2004). High volume industrial production of luxury goods versus relatively slow local economic growth led to increasing emphasis on export sales to reach customers in other countries, which is reflected in the global operation base of many of today’s luxury companies (ibid.). Through the growth of business in the twentieth century, these companies broadened their customer base and earned a universal reputation for their “superior quality, durability, performance and design” (Brun & Castelli, 2013). This led to the introduction of new perspectives on the concept of luxury, which do not ‘de-moralize’ luxury (Berry, 1994), but “couples luxury or refinement with happiness and virtue” (Armitage & Roberts, 2016).

Nowadays, the brand identity of such companies is in itself a symbol of luxury. In other words, although the quality of the product or offering is still vital, the concept of luxury has become increasingly bounded within marketing and brand communication.

So, what makes certain brands or products ‘luxury’? Adam Smith (1776) refers to luxury as “consumption of luxury products” and proposes the classification of consumption as: i) “necessary consumption to maintain life”, ii) “basic consumption for normal growth and prosperity of people and communities”, iii) “affluent consumption of goods that are not essential for growth and prosperity” and iv) “luxury consumption of goods that are in limited supply, difficult to procure and/or very expensive” (in Berthon et. al, 2009).

Other sources in literature do not limit the concept of luxury to rare and very high-priced products. For example, Kapferer (1997) suggests the qualities of a luxury brand as “quality, beauty, sensuality, exclusivity, history, high price, and uniqueness”, whereas, Antoni et al. (2004) offer a list covering “excellence, brand aura, and desirability”. Reinmoller (2002) distinguishes luxury products from standard products by claiming that luxury products exceed the level of 'standard products' by "use of material, processes, packaging, distribution and promotion" to provide "pleasure and indulgence". Brun and Castelli (2013) also investigated the constitution of luxury products and brands, and offered a more comprehensive list of answers, which they call "the critical success factors of luxury (CSF)" – proposed as a combination of selected definitions of luxury brands and products found in the literature. Under the CSF, a luxury product or brand should have the following aspects (ibid):

- 'consistently delivering/ consistent delivery of premium quality;
- heritage of craftsmanship;
- emotional appeal (going beyond the technical specifications of a product)
- global reputation of the brand
- an association with a country of origin (e.g. Swiss watches);
- superior technical performance (e.g. luxury sports cars such as a Porsche Cayman);
- elements that establish uniqueness/exclusivity (e.g. exclusivity generated by the specific manufacturing method, such as slightly uneven surfaces of mouth-blown glass vases);
- the creation of a lifestyle (e.g. the "luxury of spontaneity" concept of Bentley Motors, which suggests specific routes in different continents to be explored by Continental GT customers)

2.3.2 Luxury Values

In this section, we explore the particular qualities or concepts (e.g. desirability, exclusivity, indulgence) that luxury brands and products are associated with. The intention is to lay foundations for a structured approach towards designing for luxury product experience, by exposing the dimensions that define "luxury" in the context of consumer products. These dimensions are discussed as "luxury values". Studies within the field of marketing – which has a direct link to product design – are found to focus on up to four main strands of luxury values, namely: 1) **financial value** (Wiedmann et al., 2013), 2) **functionality** (Reddy & Terblanche, 2005) **or functional value** (Berthon et al., 2009; Wiedmann et al., 2013), 3) **symbolic** (Berthon et al., 2009; Reddy & Terblanche, 2005) **or social value** (Wiedmann et al., 2013; Kapferer and Bastien, 2009), and 4) **experiential** (Berthon et al., 2009)**, individual** (Wiedmann et al., 2013) **or personal value** (Kapferer & Bastien, 2009). These main strands are brought together in Figure 2.6.

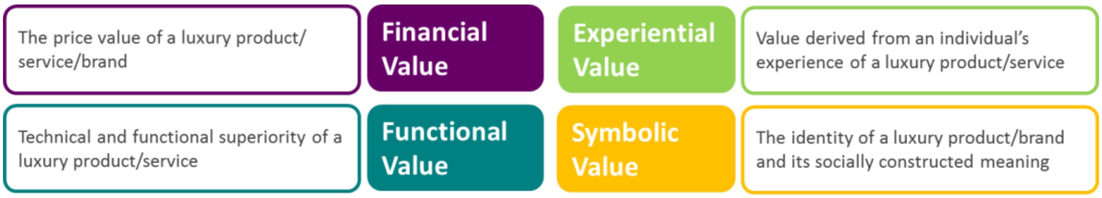


Figure 2.6 Four luxury values

2.3.2.1 Financial value

Financial value is directly related to the monetary worth of a product (Ahtola, 1984). Wiedmann et al. (2009) claim that financial value does not always have to be with reference to the point-of-sale price, it can also refer to an investment value (e.g. an art object predicted to increase in financial value over time).

2.3.2.2 Functional value

Purchasers of non-luxury products of course expect that their purchases work properly. In the case of luxury products, the expectation is of 'perfect' functioning and service. This expectation overlaps with the core benefits that Wiedmann et al. (2013) lists: quality, uniqueness, usability, reliability, and durability. The core benefits are provided through design details that combine the highest quality materials, technology, engineering, etc. Reddy and Terblanche (2005) conclude that for some brands (e.g. Porsche), the value placed on technical superiority is a key brand attribute – thus the functional value of Porsche cars is a principle determinant of their luxuriousness. Berthon et al. (2009) state that every luxury brand has its material embodiment and the functional value is defined by how the brand's products perform and are experienced in use in the material world, rather than what the product 'represents'.

Figure 2.7 Screenshots from the promotional video underlining the functional value of Bentley Bentayga (Bentley Motors, 2017)

Functional value is crucial to luxury car manufacturers, whose commercial success is based on superior performance and technical expertise. To illustrate, Bentley Motors' Bentayga SUV (Sport Utility Vehicle) was released as the world's fastest SUV, with a top speed of 301kph (Figure 2.7). The vehicle is promoted by the company "with innovation at its heart, it displays unprecedented power, speed and efficiency, setting new standards in the SUV sector." (Bentley Motors, 2015).

2.3.2.3 Symbolic value

Symbolic value can be defined as the creation of meanings through exposure to luxury brands, products or services. Symbolic value has two aspects: i) meaning created by a brand to symbolize its identity to society, and ii) socially constructed meaning that is assigned to the consumers of a particular brand by society. To exemplify, as Berthon et al. (2009) claim, "…a Ferrari may signal wealth, prestige, and performance, and it can be used to constitute and reinforce the owner's self-image as well."

Figure 2.8 The hand-finishing processes of Patek Philippe based on skills passed through generations (Patek Philippe, 2018)

Luxury brand identity is based on attributes including wealth, prestige, heritage, craftsmanship, superior quality, expertise, country of origin, uniqueness, etc. The luxury brands may place different emphasis on these attributes and prefer different strategies in relation to their promotion. For example, Montblanc (predominantly known for its luxury pens and watches) constructs narratives based on its "heritage of craftsmanship" (Brun & Castelli, 2013) and explains this as "creating an invisible bond between craftsmen's souls and their customers 'soul' (Montblanc, n.d). Craftsmanship is manifested in the luxury product in a very tangible way; however, it may not be always appreciated through sensory perception by the customers. What makes the heritage of craftsmanship a symbolic value is the appreciation of the fact that the product is hand-made and unique. Another strategy for the brand identity communication can be exemplified with using the identity and life-style of a celebrity with distinguished achievements. Rolex promotes its superior quality by designing a showcase watch – the Rolex Deepsea Challenge model – to accompany James Cameron in "his journey to deepest place on earth" (2012). The unique brand identity can also be communicated via the established set of icons or patterns (Grigorian & Petersen, 2014). People can identify a luxury product as a Chanel form logo (the intertwined C's), or the Chanel-specific "little black dress", and the number five (Grigorian & Petersen, 2014). As another strategy, brands can emphasize connections and affinity to their country of origin. Kapferer and Bastien (2009) elaborate on this, claiming that a luxury product is a small fragmentation of the culture from which/where it is produced. A specific geographic location can play a significant role in delivering exclusivity in a particular luxury product sector. For example, as with many Swiss watchmakers, Patek Philippe operates within the watch-making heritage of Geneva, which became known as a major centre for the creation and production of fine timepieces from the 18th century (Figure 2.8).

All these strategies are examples for how symbolic value contributes to luxury brand perception. Having said that, symbolic value can also be formed – as suggested by Reinmoeller (2002) – within social settings, through repeated interaction between people sharing similar interests and knowledge. Kapferer and Bastien (2009) also touch upon this, where membership of a particular group or community is reached through a common usage and ownership of luxury products – in other words, the concept of 'social luxury consumption'. In such instances, people use luxury brands to create a self-image, to present their wealth, prestige, au courant taste etc. to others, and to become conspicuous within social circles (Vigneron & Johnson, 2004). To summarize, relatedness to the luxury network creates a chance for identification of the self as the user/consumer of the luxury products; that is why social value is presented as part of the symbolic value.

2.3.2.4 Experiential value

Experiential value is related with an individual person's experience with a luxury product. This experience involves "sensations, feelings, cognitions and behavioural responses" evoked by a specific "design and identity, packaging and communications" (Berthon et al., 2009, p.10).

Figure 2.9 Montblanc M pen (Montblanc, n.d.)

Kapferer and Bastien (2009) discuss experiential value under their heading 'personal luxury consumption', implying that luxury consumption is for individual satisfaction. According to Wiedmann et al. (2013) individual satisfaction includes not only materialistic aspirations and hedonic motives but also the strengthening of a person's self-identity. Experiential value depends on the subjective taste of customers, and deals with the personal, hedonic value that is found in a brand (Berthon et al., 2009). For example, some Bang & Olufsen customers may choose to buy a loud speaker for the high-fidelity sound it offers, whereas others may choose that particular speaker for its distinctive design and manufacturing details. Another example is a Montblanc M pen (Figure 2.9), offering noticeably different experiences in use, such as the iconic 'sound' of its cap, comfortable writing, and automatic alignment of the cap and the body – each of which will appeal in different measures to different customers.

Experiential value is not only about qualities embodied within a product, but also about the wider presentation and offering of a product. The design and ambience of the shop that a product is presented in, as well as the interaction with salespeople, can contribute to (or detract from) the feeling of luxury as a sense of refinement, contentedness and exclusiveness. Creation of experiential value by luxury product presentation is exemplified by Grigorian and Petersen (2014) with the Le Labo perfume experience. Le Labo offers a tailor-made experience to its customers by preparing perfumes in front of them. This 'unique ritual' (ibid.) concludes with perfume bottles personalized with the customer's name (Figure 2.10).

Figure 2.10 The Le Lebo perfume experience (The Huffington Post, 2013)

2.3.3 The Relationship among the Luxury Values

Whilst the four values have been explained individually, it is worth noting the possibility that the values may also influence each other, such as a specific value contributing to the creation of other values or one product property becoming associated with more than one value.

Financial value is regarded as having a significant effect on other values, since all other values are the result of brand investment through money and time. These investments are reflected in the high retail price of luxury products. A brand can initially aim to create a product with a high financial value, or it can prioritize other luxury values that will, over time, build a high financial value. The relationship between financial value and other values is presented as follows.

- **Financial and Functional Value:** Dubois et al. (2001) point out high price as the indicator and result of excellent quality. Functional value derives from a good combination of design, high quality materials, advanced technologies and engineering. All these aspects have an unavoidable financial cost due to time, access to expertise, investment in research and development, etc.
- **Financial and Symbolic Value:** High financial value makes a luxury product accessible only to a minority of people, which in turn converts that luxury product into a symbol of wealth. Vigneron and Johnson (2004) name this process as "conspicuous consumption", which corresponds to having and using luxury brands as a means of social representation and status. The symbolic value of the well-established luxury brands value also justifies and determines the financial value of the product.
- **Financial and Experiential Value:** While making investments, luxury companies consider all production and consumption phases ranging from iconic design development to end-product advertisements, from the shopping experience to concierge. These investments enhance the experiential value, but also come at a financial cost, which is inevitably passed on through high retail prices.

The effects of functional value on other luxury values can be summarised as follows.

- **Functional and Experiential Value:** Products with high functional value help users to maintain their particular luxury lifestyle. For example, a luxury sports car (e.g. McLaren 570S) can offer such a grand tour travel experience that enables its users to explore long distances with exhilaration and adrenaline rushes thanks to its technical superiorities (quality materials and high performance).
- **Functional and Symbolic Value:** Using a luxury product with high functional value is the indicator of a refined taste that enhances one's self-representation within a social group. The expectation from a luxury product is a flawless experience in terms of usability and functionality. However, we should acknowledge the fact that the luxury products may 'function' only

because of its symbolic value. It can be also difficult to find a balance between functionality and symbolic value of a brand. For example, most of the luxury brands (including luxury automotive brands like Bentley Motors, Rolls Royce) take their symbolic value from heritage of craftsmanship, it can be a challenge to successfully integrate advanced technologies whilst conserving such heritage in design.

As all values are at some point intertwined, there is also a link between experiential and symbolic values. They might support or contradict each other depending on the context of luxury consumption.

- **Experiential and Symbolic Value:** Symbolic value is related with what a luxury brand or product means to others, whereas experiential value is defined as the meaning to an individual (owner, user). There are some cases where a person's individual experience blends into their social experience as they share the appreciation of luxury product services. For example, luxury cars not only offer the pleasure of driving and the feel of a craftsperson's touch through handmade interiors, but also the privilege of becoming a member of a 'select few' with a refined taste and a means to indulge it. Nevertheless, experiential value and symbolic value can also manifest a contrast, as in the example of wearing an uncomfortable high-heel shoe (low functional and experiential value) only because of what its brand represents (high symbolic value). This is a notable example for the argument raised by Armitage and Roberts (2016), which claims that it is not possible to set a meaning of the term 'luxury' only through objects, phenomena or acts without referring to the discursive context that defines the meaning of luxury by itself.

2.3.4 Luxury Values vs. Qualities of Experience

This section will discuss the luxury values in relation to pragmatic-hedonic qualities of UX, ten human needs, and the four pleasures. The previous section explained how these values influence each other or how the customers of the luxury products may prioritise one value over the other based on the context. Such relationship applies to all qualities of experience presented in Table 2.3. However, by looking at the scope and definition of each luxury value, we can argue that specific luxury values map onto specific qualities of experience more.

Table 2.4 demonstrates which luxury value corresponds to which pragmatic/hedonic quality, need or pleasure. This section will discuss these connections by going through each luxury value in order.

Table 2.4 Luxury values vs. the qualities of user experience

Luxury Values	**Hedonic - pragmatic qualities of UX** (Hassenzahl 2003)	**AttrakDiff2 Questionnaire** (Hassenzahl et.al, 2003; Hassenzahl et.al, 2015)	**Ten human needs** (Sheldon et al., 2001)	**The four pleasures** (Jordan, 2000)
Functional Value	**Manipulation (Pragmatic Quality - PQ)** Utility and usability	Technical—human Complicated—simple Impractical—practical Cumbersome—straightforward Unpredictable—predictable Confusing—clearly structured Unruly—manageable	**Competence - effectance** **Security - control**	**Psycho-pleasure**
Symbolic Value (Social Value)		Isolating—connective Alienating—integrating Separates me—brings me closer to people	**Relatedness - belongingness**	**Socio-pleasure**
	Identification (Hedonic Quality - HQ-I) Communicating an identity	Unprofessional—professional Tacky— stylish Cheap—premium Unpresentable—presentable	**Influence - popularity**	
Experiential Value (Individual Value)	**Stimulation (Hedonic Quality - HQ-S)** Providing new impressions, opportunities, and insights	Conventional—inventive Unimaginative—creative Cautious—bold Conservative—innovative Dull—captivating Undemanding—challenging Ordinary—novel	**Pleasure - stimulation**	**Psycho-pleasure**
			Physical thriving	**Physio-pleasure**
	Evocation (Hedonic Quality) Provoking memories		**Self-actualizing - meaning**	**Ideo-pleasure**
			Self-esteem - self-respect	
			Autonomy - independence	
Financial Value			**Money - luxury**	

2.3.4.1 Financial value vs. qualities of user experience

Financial value is the price of the luxury product. In this section luxury values are discussed in relation to the user experience. Therefore; regarding the financial value, we should discuss how the experience of the luxury product relates to its price. It is well explained by Sheldon et al. (2001) who defines ***money-luxury*** as ownership of the nice possessions without bothering their price. As mentioned earlier, the concept of luxury cannot be reduced to the financial value. It can be claimed that financial value maps onto the *money* aspect of "money-luxury", but it's not enough to cover what luxury is.

2.3.4.2 Functional value vs. qualities of experience

As mentioned earlier, functional value is associated with how the luxury products perform (Berthon et al., 2009); however, there is not enough reference to how the product enables users to perform the functional tasks. In other words, the technical superiority and the functionality is more emphasized than the usability and utility aspect of the product. However, a luxury product can only deliver a functional value to its users only when it is used and only when it is usable. That is why the functional value is linked with the ***pragmatic quality***. Through usability and utility of the product, the users can accomplish their pragmatic goals*,* which is expected to make them feel ***competent*** and in ***control***. As such the experience can deliver ***psycho-pleasure.***

2.3.4.3 Symbolic value vs. qualities of experience

Symbolic value has been introduced both as the identity of the luxury brand/product and its socially constructed meaning. This definition perfectly overlaps with the ***hedonic quality-identification***, which refers to the product's ability to communicate identity. Identification has a social aspect in its definition, because the communication of an identity matters in a social context. That's why symbolic value and identification is also connected with the "social" side of the user experience; namely ***relatedness-belongingness, influence-popularity*** as well as the ***socio-pleasure.***

2.3.4.4 Experiential value vs. qualities of experience

Berthon et al. (2009) define the scope of the experiential value as "sensations, feelings, cognitions and behavioural responses", which may correspond to all hedonic qualities of the product. However, there is also an emphasis on how the product is experienced *individually* for this luxury value, which helps us to differentiate the hedonic qualities that make more sense in the social context (e.g. identification) from the experiential value. Functional value - related qualities, needs and pleasures can also be separated from experiential value because of the very distinction of hedonic vs. pragmatic. Experiential value is the luxury value with the largest scope of hedonic qualities, needs and pleasures. Due to its reference to hedonic qualities of the product, in Table 2.4, it is mapped onto all remaining hedonic qualities (***stimulation*** and ***evocation****)* and the related needs and pleasures *(****psycho-pleasure*** and ***ideo-pleasure****).* The definition of the experiential value also includes the *sensations*, which goes beyond the emotions and cognitions. Therefore, it is also associated with ***physical thriving*** and ***physio-pleasure*** in Table 2.4.

2.4 Contemporary Automotive Infotainment Solutions to Empower Front-Seat Passengers

This section of the thesis was presented as conference paper-proceeding (Sen et al., 2018) with the same title at DRS (Design Research Society) Conference, held between the 25th and 28th of June 2018 in Limerick, Ireland. All sub-sections include passages that are quoted verbatim with further additions from the literature.

This research elaborates on the front-seat passenger's user experience in a luxury automobile within the scope of the infotainment system. In-vehicle infotainment systems are the parts of automotive HMI (human-machine interface) that provide 'information' and 'entertainment' services (e.g. navigation, media player) to car occupants. Traditionally, these automotive user interfaces have been designed within the limitations of 'driving activity', since drivers have been the main controllers of the vehicle. This has resulted in automobile interiors and infotainment systems which neglect the front-seat passenger. Nevertheless, (front-seat) passengers may spend as much time in the car being driven around but without having the means to entertain themselves. Within the shared experience of mobility, passengers have fewer distraction issues and they can concentrate on more varied stimuli. Their physical access to diverse parts of interior is also not as limited as that of the driver. These opportunities encourage us to rethink the way passengers interact with the infotainment system and enrich the infotainment features in a way that it will also appeal to front-seat passengers' needs and interests. As mentioned earlier, we explain this motivation as "empowering front-seat passengers" in this research, which means increasing their involvement in the car journeys by providing them with the means that will add both pragmatic and hedonic values to their travel experience.

The section provides an analysis on the R&D efforts in academia and automotive industry within the scope of "automotive infotainment solutions empowering front-seat passengers". It refers to passenger-oriented automotive UX studies and a detailed technology review of a selection of concept cars introduced at the Geneva Motor Show (2015-2016), Frankfurt Motor Show (2015), and Consumer Electronics Show (CES) (2015-2016).

It is important to mention that the introduction of autonomous driving enables drivers to act as front-seat passengers as well. To meet this challenge, automobile manufacturers have started to come up with interface solutions that will fill that gap created by the elimination of the driving task. This paper will draw on such solutions as part of passenger empowerment, although the distinction between the driver and front-seat passenger continues in autonomous car concepts with fourth level autonomy where someone needs to take control of the car when autonomous driving option cannot be used.

2.4.1 Front-Seat Passenger-Oriented Studies in Automotive UX Literature

When we analyse (front-seat) passenger-oriented studies in automotive UX literature, there are two main approaches: i) emphasis on the driver and front-seat passenger collaboration, and ii) emphasis on the front-seat passenger and investigation of what automotive user interfaces can offer them beyond enabling their assistance to drivers in driving-related tasks.

2.4.1.1 Driver and front-seat passenger collaboration

The collaboration between driver and front-seat passenger is mainly handled through using the navigation system together. To exemplify, Perterer et al. (2015) introduce a tablet-based navigation app concept and prototype "Co-Navigator" to be used by front-seat passengers. The app provides 1) map overview, (2) turn by turn instructions, (3) satellite image including pictures of demand situations and POIs, as well as (4) hazard warnings for the entire trip. The analysis of the user studies with Co-Navigator app showed that the most appreciated functionalities for the collaborative navigation were the map overview, the upcoming hazard warnings (e.g. road constructions, unmarked crosswalks) of which navigation challenge levels are shown in the application with colour-coded "demand markers", and the POI images from different directions presented in cover-flow style. They also point out design recommendations to improve these navigation systems; such as using the context information in instructions (e.g. integration of environment descriptions instead of metric definitions) and providing shared navigation (e.g. making the information visible both to the driver and the passenger) to improve the communication.

Rümelin et al. (2013) also demonstrate a system to enable driver-passenger collaboration by letting front-seat passenger deal with secondary navigation-related tasks, which are too much to handle for the drivers. The results of user-evaluations of this system show that the occupant (either the driver or the passenger) executing the defined task felt more involved; yet, the level of control increased for both car occupants when the passenger provided support in the task.

Studies regarding the collaboration between the driver and front-seat passenger in navigation tasks also include "Where Should I Turn? Moving from Individual to Collaborative

Navigation Strategies to Inform the Interaction Design of Future Navigation Systems" by Forlizzi et al. (2010) and "I need help! Exploring Collaboration in the Car" by Gridling et al. (2012). Forlizzi et al. (2010) presents the results of the qualitative user study, which was conducted as observation of the practice of collaborative navigation in automobiles with three groups of teams: i) parents and their teenage children, ii) couples, and iii) unacquainted individuals. As a result, they present varied themes to explain the collaboration. They observed "group differences in collaboration" such as: i) parents adopting a teacher role for the teenage drivers, ii) couples with more efficient and less formalized information exchange strategies despite the situations where the driver takes the role of the navigator; and iii) unacquainted individuals with more formalized communication and the cyclical 'prompt-manoeuvre-confirm' interactions. Other themes for the collaboration include "overlap in social and task roles", "situating the route in experience" (e.g. use of landmarks or familiar places as a reference), and "patterns in conversation" (e.g. timing of the navigator's help). Referring to these themes, they also present design recommendations to improve navigation systems. They include "varied and flexible information for the drivers", "more interactivity in timing and manner of information delivery" and "use of prior experiences" (ibid.).

The results of the study conducted by Gridling et al. (2012) also demonstrates that the nature of relationship and trust among the front-seat occupants affects the frequency of assistance. They also conclude that the intensity and the patterns for assistance vary depending on the contextual situations such as driver's mental state or the familiarity of the environment.

Another study called "Gaze Assist" by Trösterer et al. (2015) explore the eye-gaze detection as a new way of sharing information between the front-seat passenger and the driver, since the sitting positions of these two front-seat occupants and driver's need to keep the eye on the road do not allow them to have a natural face-to-face communication. To facilitate the communication and the collaboration, the system works in a way that the eye gaze of the front-seat passenger is captured and visualized for the driver to show exactly where the front-seat passenger looks. In this study they compare two different visualisation techniques (LEDs at the bottom of the windshield vs. dots on the screen) and reach to the conclusion that while the LED visualisations is better to avoid driver distraction, dots perform better in terms of visual accuracy and control of the front-seat passenger. The use cases for front-seat passenger's "gaze assistance" are illustrated as a warning to the driver for upcoming hazards or giving support in navigating in an unfamiliar region (ibid.).

2.4.1.2 "Passengering" beyond driver-passenger collaboration

This category of research puts all passengers as the focal point and analyses their needs and activities as passengers. In this regard, Inbar and Tractinsky (2011) propose that IVIS (Inter-vehicle information system) should be made more accessible to passengers so we can reduce boredom and increase a sense of inclusion of the front or rear-seat passengers. They also argue that making in-car information more accessible to passengers can eliminate the need for the driver to share trip-related information with passengers, which reduces distraction and information load of drivers.

In addition, Lee et al. (2015) present a study on a split-view navigation system and list the information needed or prioritized by the driver and front-seat passenger individually during the phases of the journey. Lee et al. (ibid., p. 488) presents the definition of the split-view technology (Figure 2.11) as:

> … a type of backlit colour active matrix display (TFT-LCD) where two different images are displayed simultaneously over pixels adjacent to a screen. A front side of the display is divided into two images that can be seen differently according to seat position, thereby watching two different contents simultaneously (Moon, 2006, in ibid.).

Figure 2.11 Mercedes-Benz split-view display (eMercedesBenz, 2008)

Lee et al. (ibid.) conducts a focus group to determine the circumstances when drivers and front -seat passengers need to see the navigation system (Table 2.5), so that they can define the navigation information that should be presented to the driver and the front-seat passenger simultaneously under these circumstances.

Table 2.5 Circumstances when driver needs to see navigation system (Adapted from Lee et al., 2015)

Driver	Front-Seat Passenger
When speeding camera is present	When assisting support for driver is required
When traffic congestion occurs	When traffic congestion occurs
When driving direction needs to be changed	When time and distance to destination are required.
When a vehicle enters a tollgate	When surrounding information is required
	When destination-related information is required

Lee et al. (2015) present the information that front-seat passengers require during separate phases of the travel (Figure 2.12). They also visualize how the information required by the driver and the front-seat passenger can be simultaneously presented in such split-view navigation system. Figure 2.12 presents the proposals for the graphical user interface for such system based on the two circumstances mentioned in Table 2.5: during traffic congestion (Figure 2.12, bottom-left) and entering the toll gate (Figure 2.12, bottom-right).

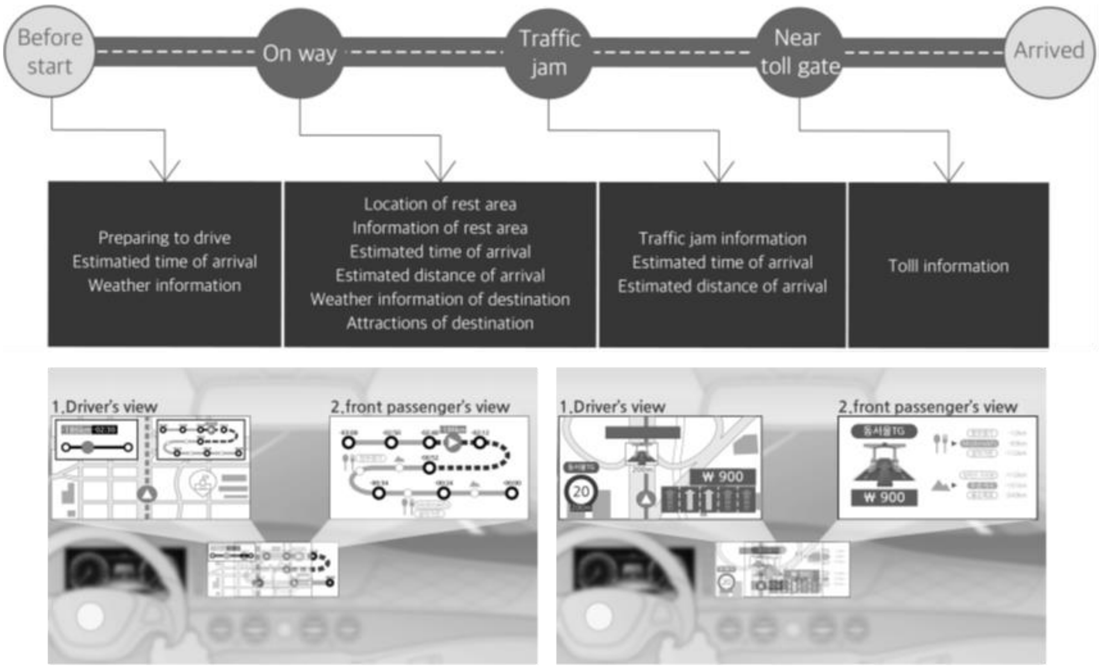


Figure 2.12 The navigation information required by the front-seat passenger during the journey, driver's and front-seat passenger's view during traffic congestion and while entering the toll gate (Adapted from Lee et al., 2015)

The examples included thus far relate to the shared use of the available in-car information with passengers. Nevertheless, there are also academic efforts to understand (front-seat) passengers' further needs and interests beyond the provision of travel information alone. Osswald et al. (2013) presents a probing study conducted with front-seat passengers. They conducted the study by approaching front-seat passengers in petrol stations and giving them the probing materials to be used and returned on their next time in the station. The probing materials (the booklet to be filled and other materials for reference) comprised varied themes for front-seat passengers to think about: "good vs. bad front-seat passenger cockpit, information desire, information sharing [with the driver], visions for a front-seat passenger cockpit, front-seat passenger needs" (ibid, p.5).

Based on the analysis of the probing materials, they demonstrate a cluster of the modalities (e.g. interface modalities, radio, display); services (e.g. navigation, internet, social media, games); context (e.g. weather, speed, front-seat passenger area); and information (e.g. surroundings, TV, distance left/travelled) the front-passengers deal with or mention about the most. Table 2.11 can be referred to see the contribution of Osswald et al. (ibid.) in definition of front-seat passenger-oriented infotainment features. In their paper, they also present the results of a design workshop where they asked a group of industrial designers to ideate front-seat passenger cockpit solutions within the light of the research results. Figure 2.13 demonstrates one of the ideas generated in the workshop, which suggests a thumb-controlled device on the armrest, a simple status display on the passenger dashboard and a rooftop display to enjoy the in-car infotainment in privacy.

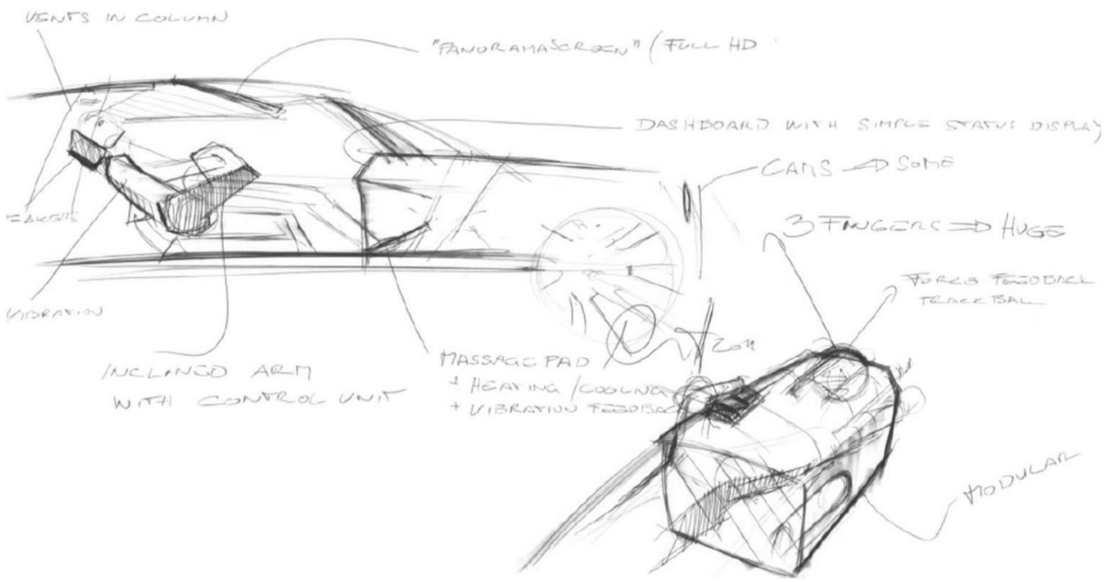


Figure 2.13 Interface solutions located on the armrest, passenger dashboard and the rooftop (Adapted from Osswald et al., 2013)

2.4.2 Analysis of (Front-Seat) Passenger-Oriented Infotainment Solutions

Previous sections have briefly introduced the approaches followed in the literature regarding the front-seat passenger experience. This section will provide a deeper analysis and deconstruction of the passenger-oriented academic and industrial R&D efforts, so that we can position their contributions within varied dimensions of the UX. Therefore, while analysing the passenger-oriented automotive interface solutions, Hassenzahl (2010)'s *how, what* and *why* levels of interacting with technology will be referred. As mentioned earlier, the model investigates how a user connects his/her-self to the world through an activity with a three-level goal hiearchy. In this model, *what*' dimension for 'do-goals' refers to the tasks to be completed or a concerete goal to be achieved by users, which can defined as the functionality. At the lowest level, there is ‘how’ dimension for ‘motor-goals’ which involve all the operational steps that user has to go through while interacting with the product. At the highest level, there is ‘why’ dimension for ‘be-goals’ which is about the meaning, motivations and emotions related to that activity.

The previously mentioned research can be referred again to exemplify how these diverse levels of interacting with technology are studied in literature. The use of emerging technologies (e.g. eye-gaze recognition, split-view displays) in front-seat passengers’ in-car interactions illustrates the investigation of the *how* dimension, because embodiment of these technologies has a direct influence on how we interact with the interfaces. On the other hand, the *what* dimension has been studied through the identification of the type of information or services that front-seat passengers are interested in. These studies have also touched upon the *why* dimension by explaining the positive effects of these applications on users such as ‘reduced boredom’ or ‘sense of inclusion’. It is important to mention that all these dimensions are linked; that is improvements in interactions and functionalities contribute to a pleasant user experience (*why* dimension); and thinking about what makes a pleasant experience helps designers come up with appealing interface designs and functionalities.

The examples can be expanded with the passenger-oriented solutions that automotive companies are planning to integrate into future cars. Therefore, concept cars introduced in Geneva Motor Show (2015-2016), Frankfurt Auto Show (2015), and Consumer Electronics Show (CES) (2015-2016) were investigated with an eye to reveal the technologies and passenger-oriented solutions they have recently integrated and/or have visions to include. The official websites of the auto-shows as well as other online technology and automotive design sources e.g. Car Magazine, CNet, Digital Trends, and YouCar were studied. Car manufacturer web-sites were also referred when further information was needed for a specific model introduced in these shows. In total, 241 cars (59 concept cars, 182 production cars to be released in near future) were reviewed. Please check Appendix 1 to see the full list of the cars included in the review.

Each car has its own prominent features and they present varied innovations in styling, performance, alternative energy usage, and automotive HMI (human-machine interfaces within the car). Based on the scope of the research, 13 cars offering new concepts for in-car interactions were selected for further analysis. The selection criteria were based on two questions:

1. Do the in-car interactions (automotive HMI) demonstrate anything beyond what exists in production cars?
2. Does the car provide any (front-seat) passenger-oriented infotainment solutions?

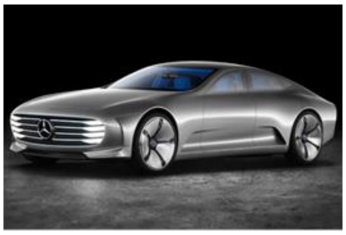
a. Audi Prologue
(Geneva Motor Show, 2015)

b. BMW Vision Next 100
(Geneva Motor Show, 2016)

c. Ferrari GTC 4 Lusso
(Geneva Motor Show, 2016)

d. Opel GT Concept
(Geneva Motor Show, 2016)

e. Skoda VisionS
(Geneva Motor Show, 2016)



f. Mercedes IAA Concept
(Frankfurt Motor Show, 2015)

g. Porsche Mission E
(Frankfurt Motor Show, 2015)

h. Volkswagen Golf R Touch
(CES 2015)

i. Mercedes F015 Luxury in Motion
(CES 2015)

j. BMW i8 Vision
(CES 2016)

k. KIA DriveWise
(CES 2016)

l. Volkswagen BUDD-E Concept
(CES 2016)

m. Volvo Concept 26
(CES 2016)

Figure 2.14 Selected concept cars, including the cars with **autonomous mode**

The 13 cars that successfully fulfilled one or both of these criteria (Figure 2.14) include Mercedes F015, Volkswagen Golf R Touch (CES 2015); BMW i8 Vision, Volvo Concept 26, Volkswagen BUDD-E, Kia DriveWise (CES 2016); Porsche Mission E, Mercedes IAA Concept (Frankfurt Motor Show, 2015); Audi Prologue (Geneva Motor Show 2015); Ferrari GTC 4 Lusso, BMW Vision Next 100, Opel GT Concept, Skoda VisionS (Geneva Motor Show 2016).

Infotainment systems that are dedicated to the use of front-seat passengers do not yet exist in production cars, we can discuss such versions of infotainment only in the context of future car journeys. Therefore, detailed analysis of concept cars is important to identify the trends in automotive user interfaces, and to investigate the use of interaction technologies and infotainment features envisioned for future travel scenarios.

The technology review of the selected concept cars was conducted through a content analysis of a varied collection of media including the explanatory texts, visuals and videos, which demonstrate the interactive features of the car interfaces. The categorization of the relevant content was mainly based on the passenger-specific automotive user interface solutions, the interaction technologies used for information provision and input, and the car infotainment features targeting the front-seat passengers / occupants (in shared systems). Further categorization of the results and the discussion can be found in the following section.

2.4.3 Results & Discussion

In this section, based on the model of Hassenzahl (2010) that explains the different levels of interacting with technology (*why-what-how*), this section will first investigate the *how* level – 'front seat passenger infotainment interactions'. With regards to this level, it will introduce i) new control and display configurations in the car's interior that empower (front-seat) passengers, ii) trends in automotive user interfaces and iii) mostly used interaction technologies in selected concept cars. For the latter two (ii, iii) passenger vs. driver-oriented solutions will not be differentiated, because the very same technology or interface can be reconsidered as control and display of front-seat passenger infotainment systems. Secondly, it will focus on 'front-seat passenger infotainment features' (the *what* level). It will provide a categorization of passenger infotainment features based on passenger interests identified in the literature and passenger-oriented infotainment trends presented in the technology review. The categories include information, communication, and entertainment. Finally, it will touch upon the *why* level– 'enhancement of front-seat passenger journeys'. In this part, we refer to studies, which identify the types of positive effects that these solutions have on front-seat passengers. It will also discuss in what ways the efforts mentioned under *how* (the way we interact the system) and *what* (the infotainment features) dimension could enhance the front-seat passenger journey experience.

2.4.3.1 Front-seat passenger infotainment interactions

This section will provide the analysis of the automotive user interface solutions presented in the literature and the technology review with a focus on how (front-seat) passengers are expected to interact with the infotainment systems. The section includes the following headings: i) New interior control and display configurations that empower (front-seat) passengers; ii) Mostly used interaction technologies; and, iii) Trends in automotive user interfaces.

a) New interior control and display configurations that empower (front-seat) passengers:

Table 2.6 illustrates how (front-seat) passenger empowerment is achieved through different approaches in automotive user interface design. The categories range from infotainment systems dedicated to front-seat passengers (A), to more indirect solutions that integrates the front seat passenger as well to the experience of interactive infotainment systems of the cars; either through information provision extended to the front-seat passenger side (B) or by turning the whole car interior into a 'digital social space' (C).

Four concept cars out of 13 that were reviewed - Mercedes IAA Concept, Opel GT Concept, VW Golf R Touch, and Kia DriveWise - are not included in Table 2.6, as they do not provide any interface or infotainment solutions dedicated to passengers. They only have controls and displays in the central console area through which the front-seat passenger has a limited access to driver-oriented infotainment, as in the case of most of today's cars. However, they are included in the discussion of front-seat passenger infotainment interactions for their innovative approaches in automotive HMI design.

Volvo Concept 26 and BMW Vision Next 100 have been placed in category *B-Information provision extended to front-seat passenger side-* only because they provide a shared information provision to front-seat passengers through extended displays. Unlike the other two cars in this category (Porsche Mission E and BMW i8 Vision), they do not offer any front-seat passenger-specific solutions that enable them to control infotainment from their cockpit.

Table 2.6 Control and display configurations in interior that empower (front-seat) passengers

A. Infotainment screens dedicated to front-seat passenger

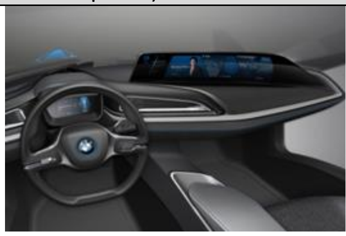

Audi Prologue


Ferrari GTC 4 Lusso


Skoda VisionS

B. Information provision extended to front-seat passenger side (Accessed by both front-seat occupants)


Porsche Mission E


BMW i8 Vision


Volvo Concept 26


BMW Vision Next 100

C. Whole car interior as a 'digital social space'


Mercedes F015


Volkswagen BUDD-E

b) Mostly used interaction technologies:

In this research, the term 'interaction technology' corresponds to the interactive features of the automotive user interfaces such as touch recognition. The information provided for each concept car does not always contain which specific technology is used to deliver the interactivity, especially for input. For example, we can gather information about the type of modality used (e.g. touch vs. gesture recognition), how it is applied in the car interior (e.g. touch sensitive armrest vs. touch screen) but cannot always identify the exact underlying technology (e.g. capacitive vs. ultrasonic touch recognition) mostly because of the confidentiality of R&D of automotive user interfaces.

Figure 2.15 summarizes the type of interaction technologies used for input and information provision in the reviewed cars, how frequently the technologies are utilized, and in what ways they are applied to the car interior. Input technologies refer to the means that are utilized to control interfaces, whereas information provision technologies correspond to any type of display or feedback that are utilized to provide information to users.

Figure 2.15 Distribution (x out of 13 cars) of interaction technologies (input and information provision) used in concept cars (circle's size represents the relative frequency)

Regarding the input technologies, it is observed that touch recognition, gesture recognition, eye-gaze recognition and audio recognition are used as a replacement of the physical controls like knobs and buttons. It was a challenging task to identify the concept cars with audio recognition, since it is not a visible feature. Therefore, audio recognition is added as a feature for the concept cars if it is mentioned or presented as type of input in the video or the reviewed text-based sources. We can claim that *at least* seven out of the thirteen cars have this feature.

The categorization of the technologies for information provision was also made based on the sensory modalities used. As can be seen in Figure 2.15, visual display types vary from currently used LCD or LED displays to curved OLEDs, flexible OLEDs, 3D panel LED projection, head up displays and shape changing displays. In addition to visual displays, information is also communicated via haptic displays (e.g. touch sensitive surfaces or touch screens with 'surface-haptics' feedback) and audio displays (e.g. audio feedback). It is important to mention that a specific technology can appeal to more than one modality or can be used for both input and information provision. For example, shape changing displays are applied as means of visual feedback in the BMW Vision Next 100 under the concept of 'alive geometry' (tiny triangular physical surfaces in motion to notify the driver about e.g. upcoming hazards); however, the very same technology has been studied as a haptic feedback or even as an input via changing shapes as well.

c) Trends in automotive user interfaces:

This section presents the most commonly used interaction technologies in concepts cars and the trends that automotive firms followed to utilize them to enhance car interfaces, interactions and interiors. The information about the trends (see Figure 2.16) are as follows:

- *Touch as the most used modality.* Automotive firms started to use touch sensitive surfaces in different zones of the car interior in addition to the touch sensitive screens in the central console and dashboard.
- *Expansion in areas and ways of information provision*. There is an expansion from the conventional information provision areas (infotainment screens on central console/dashboard, instrument clusters and HUDs at driver's side) to passenger dashboard, side doors and other surfaces of the car interior. Such expansion also applies to head-up displays, which has been rethought as a "windshield display" in concept cars. We also see novelty in the way that information is provided as in the example of "alive geometry" in BMW Vision Next 100 (2016) where tiny triangular physical surfaces in motion notify the driver about incoming dangers (BMW, 2016).
- *Increasing integration of gestural recognition.* Hand gestures are mostly utilized to control the information provided through displays expanded to the front-seat passenger side or HUDs, where the use of touch is not an option for the driver

because of the reach issue. Another motivation for the integration of gesture recognition is to decrease the number of physical controls - the visual complexity of the interior.

- *Curved displays blending into interior.* It is also observed that the aim behind the use of particular display technologies (e.g. Curved OLEDs, 3D LED Panel projection) is to eliminate the need to use flat interior surfaces just to place flat-rectangular screens on the dashboard. This brings much more flexibility to the design of the car interior and its visual aesthetics.
- *Co-located physical and digital layers.* There is an increase in interactivity of physical items in the car either through e.g. integration of LED light-based visual feedback under the mesh leather upholstery of the steering wheel (BMW i8 Vision) or HUDs which augment the outside windshield view with a digital information layer.
- *Expansion of control areas from dashboard/central console to the whole of the car interior.* As the travel scenarios change in a way that integrates more car occupants in control of interactive systems (see Table 2.6), it becomes necessary to create ready-at-hand control areas for them. That is why we see examples like touch sensitive arm-rests or touch-sensitive side doors. This trend is highly related to the "expansion of information provision", especially for interfaces where control-feedback is achieved using the same interactive element, as in the case of touch-screens.

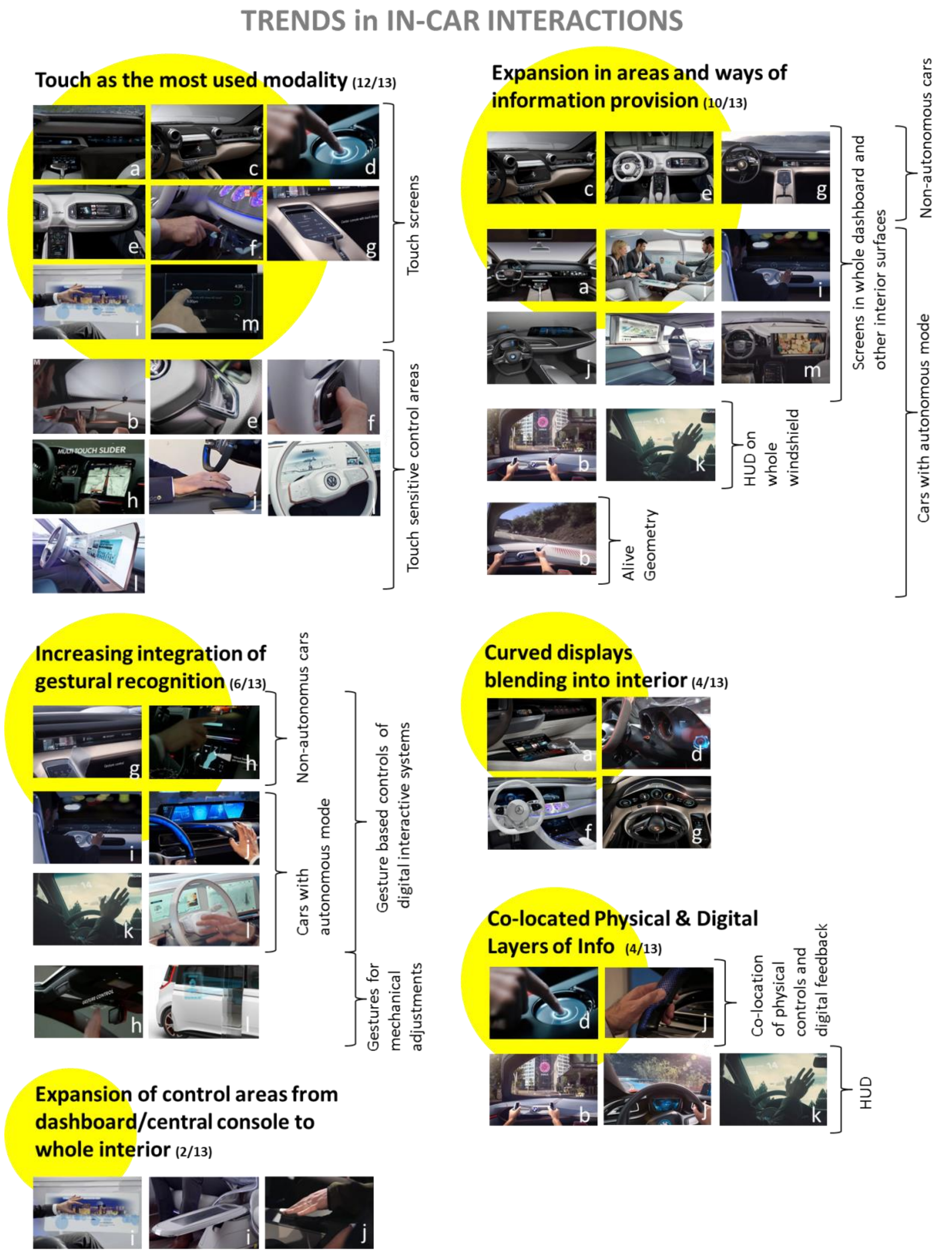


Figure 2.16 Distribution of (x out of 13 cars) of future trends for in-car interactions in concept car (circle's size represents the relative frequency)

2.4.3.2 Front-seat passenger infotainment features

The previous section covered diverse ways of accessing infotainment features in a car. This section will focus on what these infotainment features are; in other words, what front-passengers will be able to do when front-seat passenger infotainment systems are realised. The infotainment features are either shared by other car occupants (See B & C sections of

Table 2.6); or provided specifically for front-seat passengers (See the section A of Table 2.6).

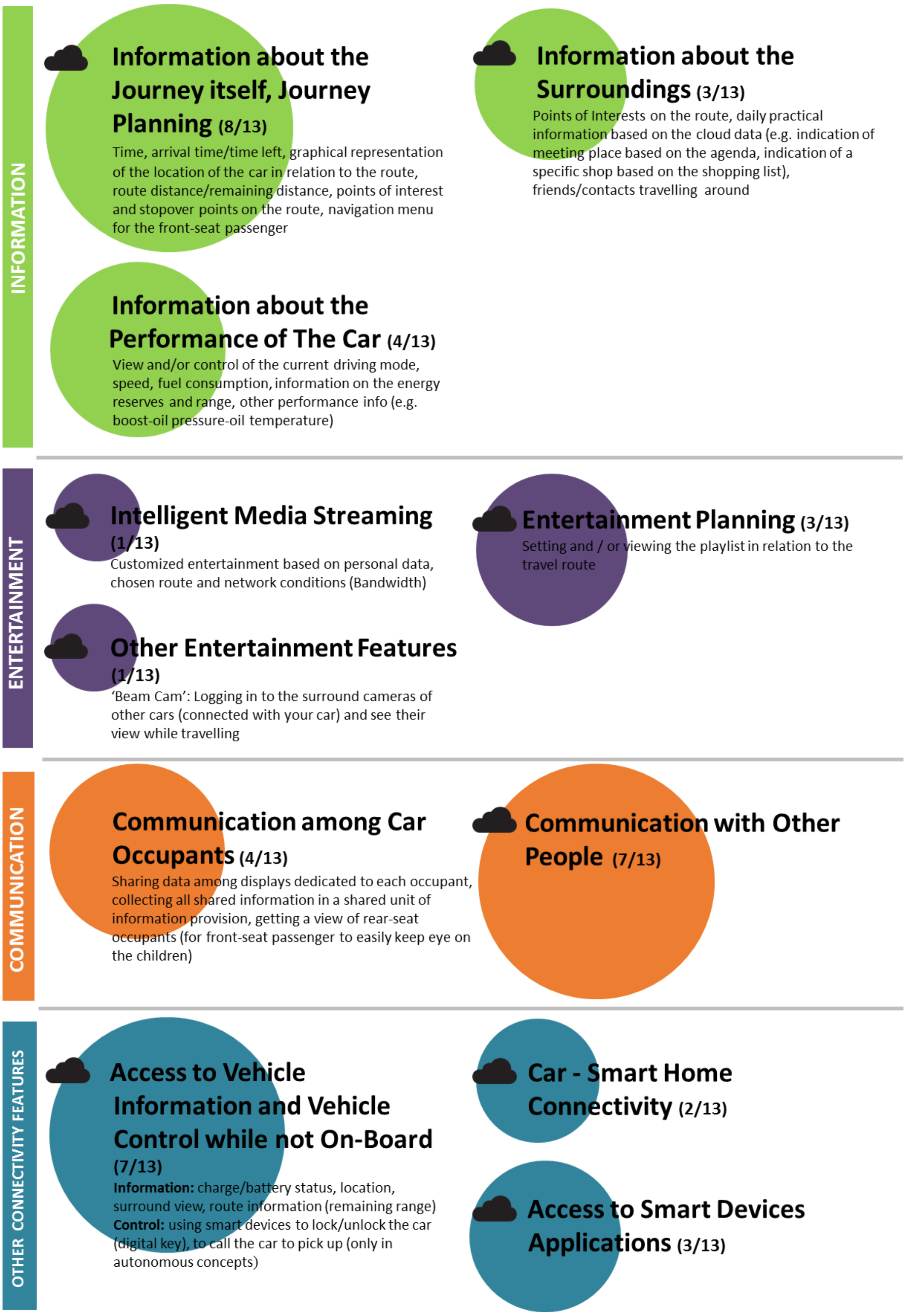


Figure 2.17 Distribution of (x out of 13 cars) of infotainment features in concept cars (circle's size represents the relative frequency)

The content analysis of the new functionalities presented in the literature and concept cars revealed three main categories of infotainment features: information, entertainment and communication. Some aspects of the infotainment features overlap with each other; therefore, it is not possible to make a strict separation between these three categories. However, the prominent attributes of each category are as follows: *Information* concerns anything that passengers would like to know or learn throughout the journey*; entertainment* relates to anything that would help to reduce the boredom of being a passenger, which, of itself is not necessarily stimulating; *communication* is about sharing things with other car occupants and other people outside the car and involving them to a specific part of travelling experience through infotainment.

Most of these features can function thanks to today's connectivity technologies and cloud systems, which create a network among the vehicle and smart devices, other vehicles and the infrastructure. Following information, entertainment and communication, this section will also shed light upon other connectivity-enabled features, which can be used either inside or outside of the car. These features are mentioned under a separate category because they are not necessarily about information, entertainment or communication; but about being able to access or control all these features while on-board or not on-board.

Figure 2.17 illustrates the list of all (front-seat) passenger-oriented information, entertainment and communication features together with the other connectivity features offered by the concept cars. It demonstrates that most of the infotainment features are enabled by connected car technologies. Another highlight is that the information and communication categories have been explored more in detail compared to the entertainment category. New entertainment functionalities presented in concept cars focus on how to organize media playlists rather than exploration of alternative entertainment features.

a) Information:

Information provided to (front-seat) passengers in the reviewed concept cars include the *i) journey and journey planning; ii) surroundings of the car*; or *iii) the performance of the car.* See Table 2.11 to view additional information categories mentioned in the literature.

i) The information about the journey itself and journey planning includes:

- Time, arrival time/time left to the destination
- Graphical representation of the location of the car in relation to the route
- Route distance/remaining distance

- Points of interest and stop-over locations on the route
- Navigation menus for the front-seat passenger

It is crucial to mention that this information is given as a part of either navigation menus or other specific menus that provide the key information about the journey without complex navigation-related features. The content and functionalities of the passenger-specific navigation menus are not clear from the concept cars-related sources we reviewed. However, from the literature we can add 'tracking journey via real-time mapping' and 'surrounding streets information' features (Inbar & Tractinsky, 2011) to the bullet points provided within this sub-category.

ii) Information about the surroundings includes:

- Cultural information (e.g. Information about the points of interest on the route)
- Daily practical information based on cloud data (e.g. indication of meeting place based on the agenda, indication of a specific shop based on the shopping list)
- Social information: Friends/Contacts travelling around

Regarding cultural information, the research of Osswald et al. (2013) presents which point of interests and other surroundings-related information are prioritised by front-seat passengers. The 'Toll gate information' example provided by Lee et al. (2015) shows that a diversity of the travel scenarios can enrich the examples regarding the information about the surroundings that needs to be provided to passengers. Connectivity-enabled daily practical information or social information is not mentioned in the literature.

iii) Information about the performance of the car include:

- View (and/or control) of the current driving mode
- Speed
- Fuel consumption, information on the energy reserves and range
- Other performance info (e.g. boost-oil pressure-oil temperature)

Fuel information also appears as a type of information that front-seat passengers mentioned in the probing study conducted by Osswald et al. (2013). While talking about sharing in-car information with passengers, Inbar and Tractinsky (2011) also give example of a Maybach car with speedometer dials attached to rear-seat passenger's side door.

Table 2.7 shows the cars that have these information features in their infotainment menus with the relevant images.

Table 2.7 Infotainment Features Empowering (Front-Seat) Passengers: Information

INFORMATION

1. INFORMATION ABOUT THE JOURNEY ITSELF, JOURNEY PLANNING

Time, arrival time/time left, graphical representation of the location of the car in relation to the route, route distance/remaining distance, points of interest on the route, navigation menu for the front-seat passenger

Audi Prologue (Road Trip, Personal Assist), Ferrari GTC4 Lusso (Navigation), Skoda VisionS (Navigation)

Porsche Mission E (Navigation), BMW i8 Vision (Navigation), Volvo (Navigation)

Mercedes F015 (Guided Path-Time, Guided Path-Places), VW BUDD-E (VW Travel App)

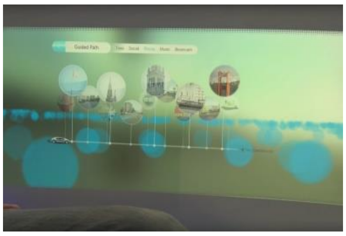
Audi Prologue

Ferrari GTC 4 Lusso

Skoda VisionS

BMW i8 Vision

Volvo Concept 26



Mercedes F015

Mercedes F015

VW BUDD-E

2. INFORMATION ABOUT THE SURROUNDINGS

Cultural information (e.g. information about the points of interest on the route)

Daily practical information based on cloud data (e.g. indication of meeting place based on the agenda, indication of a specific shop based on the shopping list)

Social information (e.g. friends/contacts travelling around)

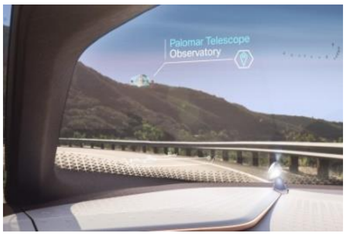
Audi Prologue (Road Trip, Personal Assist)

BMW Vision Next 100

Mercedes F015 (Guided Path-Places, Guided Path-People)

Audi Prologue

Mercedes F015



BMW Vision Next 100

3. INFORMATION ABOUT THE PERFORMANCE OF THE CAR

View (and/or control) of the current driving mode, arrival time/time left, speed, fuel consumption, information on the energy reserves and range, other performance info (e.g. boost-oil pressure-oil temperature)

- Ferrari GTC4 Lusso (Performance), Audi Prologue
- Porsche Mission E (Vehicle)
- Mercedes F015 (Conducting-Guided Path), VW BUDD-E (Head Unit_Travel Mode)

Ferrari GTC 4 Lusso

Audi Prologue

Porsche Mission E

Mercedes F015

VW BUDD-E

b) Entertainment:

Media (audio-video) players can be considered as default entertainment features in contemporary cars. What is new in concept cars regarding media playing and entertainment is enhancements brought by the connectivity. These new entertainment features include:

i) *Intelligent media streaming*: Customised entertainment based on personal data, chosen route and network conditions (bandwidth) *ii) Entertainment planning:* Setting and/or viewing the playlist in relation to the travel route)

iii) Other entertainment features (e.g. 'Beam Cam': Logging in to the surround cameras of other F015 cars connected with your car and seeing their view while travelling)

Table 2.8 shows the cars that have these entertainment features in their infotainment menus with the relevant images.

Table 2.8 Infotainment features empowering (front-seat) passengers: Entertainment

ENTERTAINMENT

1. INTELLIGENT MEDIA STREAMING

Customised entertainment based on personal data, chosen route and network conditions (Bandwidth)

Volvo Concept 26

Volvo Concept 26

2. ENTERTAINMENT PLANNING

Setting and /or viewing the playlist in relation to the travel route

Volvo Concept 26

Mercedes F015 (Guided Path-Music), VW BUDD-E (VW Travel App)

Volvo Concept 26

Mercedes F015

VW BUDD-E

3. OTHER ENTERTAINMENT FEATURES

'Beam Cam': Logging in to the surround cameras of other F015 cars (connected with your car) and see their view while travelling.

Mercedes F015 (Guided Path)

Mercedes F015

Entertainment is not a concept that is deeply explored for the front-seat passenger. Having reviewed passenger-oriented studies, we can only refer to Osswald et al. (2013), where front-seat passengers mention TV, DVD movies, games, Facebook, pictures, and YouTube as possible infotainment features. Most of these features can be provided through the connected car systems, like Apple Car Play or Android Auto, to enable access to smart device applications in car. It is mentioned under the category of ‘Other connectivity features’.

Table 2.9 Infotainment features empowering (front-seat) passengers: Communication

COMMUNICATION

1. COMMUNICATION AMONG CAR OCCUPANTS

Sharing data among displays dedicated to each occupant, collecting all shared information in a shared unit of information provision, getting a view of rear-seat occupants (for front-seat passenger to easily keep eye on the children)

Skoda VisionS, Audi Prologue

Mercedes F015, VW BUDD-E

Skoda VisionS

Audi Prologue

Mercedes F015

VW BUDD-E

2. COMMUNICATION WITH OTHER PEOPLE (AUDIO/VIDEO CALLS, MESSAGES)

Skoda VisionS (chat)

Porsche Mission E (Contacts), BMW i8 Vision, BMW Vision Next 100, Volvo Concept 26

Mercedes F015 (Connected Device), VW BUDD-E (‘Messages’ and ‘Phone’)

Skoda VisionS

BMW i8 Vision

Volvo Concept 26

Mercedes F015

VW BUDD-E

BMW Vision Next 100

c) Communication:

Communication features can either contribute *to i) communication among car occupants* or *ii) communication with other people.* Table 9 shows the cars that have these communication features in their infotainment menus with the relevant images.

i) Communication among car occupants can be illustrated as follows:

- Sharing data among displays dedicated to each occupant
- Collecting all shared information in a shared unit of information provision
- Getting a view of rear-seat occupants (e.g. for front-seat passenger to easily keep eye on the children at the back)

The above-mentioned literature about specific in-car applications developed for passenger-driver collaboration in navigation tasks can be considered as examples of infotainment features enabling communication among car occupants (See Table 11).

ii) Communication with other people is achieved in the reviewed cars via audio-video calls or text messaging.

In relation to communication with other people, Osswald et al. (2013) list Facebook, e-mail, contact list, SMS and Skype features and applications.

d) Other connectivity features:

This section refers to connected car features (Table 10), which cannot be considered only as an information, entertainment or communication feature, but can be a part of the car infotainment systems, including:

- *i) Access to vehicle information and vehicle control while not on-board:* The information that can be accessed via connected smart devices (phone or watch) consists of charge/battery status, location, surround view, and route information (remaining range). Vehicle control via smart devices can be illustrated with locking/unlocking the car (digital key) and calling the car to pick-up (only in autonomous concepts). Please note that these features are provided only to the owner of the cars, authorised drivers or driver-passengers of the autonomous cars. We believe that vehicle information access and control while not on-board can be customised for other car occupants, in our case, for front-seat passengers as well.

- *ii) Smart home-car connectivity:* Access to smart home information and controls (e.g. viewing the home security camera footage)
- *iii) Access to smart devices applications:* This feature includes systems like Apple Car Play and Google Android Auto and they are only mentioned for the concept cars to be soon released into the market (starting from 2017).

Table 2.10 Infotainment features empowering (front-seat) passengers: Other connectivity features

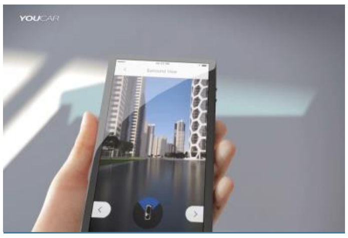
OTHER CONNECTIVITY FEATURES

1. ACCESS TO VEHICLE INFORMATION AND VEHICLE CONTROL WHILE NOT ON-BOARD

Information: charge/battery status, location, surround view, route information (remaining range)

Control: using smart devices to lock/unlock the car (digital key), to call the car to pick up (only in autonomous concepts)

Porsche Mission E

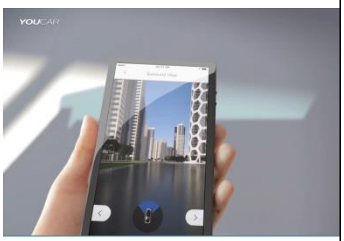


Mercedes F015

BMW i8 Vision

Audi Prologue

Porsche Mission E



Mercedes F015

2. SMART HOME-CAR CONNECTIVITY

BMW i8 Vision

VW BUDD-E

3. ACCCESS TO SMART DEVICES APPLICATIONS

Apple Car Play, Google Android Auto etc.
(Ferrari GTC 4 Lusso, Audi Prologue - 'Audi Smartphone', VW Golf R Touch)

Table 2.11 presents the resulting categories for passenger infotainment features and how they are depicted in the literature and technology review (of concept cars). The table shows that academic and industrial efforts are aligned when it comes to the identification of front-seat passengers' needs and finding solutions to fulfil them.

Table 2.11 List of (front-seat) passenger infotainment features depicted in literature vs. concept cars

Infotainment features depicted in literature	Infotainment features depicted in concept cars
INFORMATION	
Information about the Journey Itself, Journey Planning • time travelled, travel duration*, estimated time of arrival** • distance travelled, distance to destination*, estimated distance of arrival** • location of the rest area, information about rest area, attractions of destination • tracking journey-real-time mapping*** • traffic info, traffic lights*, traffic jam** • surrounding streets***	**Information about the Journey Itself, Journey Planning** • time, arrival time/time left • graphical representation of the location of the car in relation to the route • route distance/remaining distance • points of interest and stop-over points on the route • navigation menu for the front-seat passenger
Information about the Surroundings • shopping, hotel, restaurant, road signs, radar, sightseeing, toilet, gas station, activities, church, cinema, events, camping, picnic, swim, POI *, toll information (near toll gate) **	**Information about the Surroundings** • points of interests on the route • practical information based on the cloud data (e.g. indication of meeting place based on the agenda) • friends/contacts travelling around
Information about the Performance of the Car • fuel* • speedometer (Maybach example) ***	**Information about the Performance of the Car** • view (and/or control) of the current driving mode and speed • fuel consumption, information on the energy reserves and range • other performance info (e.g. boost-oil pressure-oil temperature)
Information about the Weather • weather* weather information of destination** outside temperature dial***	
News*	
Google Search*	
ENTERTAINMENT	
• TV, DVD/movies, games, Facebook, pictures, YouTube*	**Intelligent Media Streaming** **Entertainment Planning (Setting and/or viewing the playlist in relation to the travel route)** **Other Entertainment Features** • 'Beam Cam': Logging in to the surround cameras of other cars and see their view while travelling
COMMUNICATION	
Communication among Car Occupants • front-seat passenger and driver collaboration in navigation****	**Communication among Car Occupants** • sharing data e.g. route plan among displays dedicated to each occupant • collecting all shared information (e.g. playlist) in a shared unit of information provision, • getting a camera view of rear-seat occupants
Communication with Other People • Facebook, e-mail, contact list, SMS, Skype*	**Communication with Other People** • audio/video calls, text messages
[*] Osswald et al., 2013; [**] Lee et al., 2015; [***] Inbar & Tractinsky, 2011; [****] Trösterer et al., 2015; Perterer et al., 2015; Rümelin et al., 2013; Gridling et al.; 2012 and Forlizzi et al., 2010.	

2.4.3.3 Enhancement of front-seat passenger journeys

This section discusses how academic studies and automotive HMI solutions referred in earlier sections would enhance front-seat passengers' journeys. In this research, "empowerment" is used as an umbrella term to define the main motivation behind these efforts, because only when the front-seat passengers are empowered with the infotainment system we can talk about how to enhance their infotainment experience, hence their journeys. Front seat passenger's empowerment through the infotainment system means increasing the front-seat passengers' involvement in the car journeys by offering more means for getting information, entertainment, and communication to their access and control. However, this definition should not only be taken as provision of new functionalities, but also designing the aesthetics of the infotainment system interactions based on the front-seat passenger's pragmatic and hedonic motivations. This section explains in what ways these new interfaces, interactions, and infotainment features can enhance front-seat passengers' travelling experience, along with bringing empowerment to users.

The expected contributions of sharing in-car information with passengers are identified by Inbar and Tractinsky (2011) as "reduced boredom", "increased trust", and "increased sense of inclusion" for (front-seat) passengers. "Involvement" and "level of control" are also among other UX criteria that are mentioned in relation to the shared navigation systems. We can claim that studies exploring driver-passenger collaboration not only investigate pragmatic navigation solutions based on collaboration, but also aim for front-seat passengers' 'autonomy' and 'competence' (Sheldon et al., 2001; Hassenzahl, 2010) by giving them more control and responsibility in completion of driving-related tasks, 'relatedness' (ibid.) based on increased communication between front-seat occupants and 'stimulation' (ibid.).

In the section "Front-seat passenger infotainment features," we introduced these features under the categories of *communication, entertainment and informatio*n (See Table 2.11). These categories also act as concepts to identify the ways of enhancing front-seat passengers' journeys. We can link these categories to the psychological needs of the passenger as well (ibid.) Accessing the *information about the journey, surroundings and performance of the car* can provide front-seat passengers with more 'autonomy' and 'security'. It can be claimed that communication-related features like audio/video calls, access to social media accounts carry potential to increase 'relatedness' and 'popularity'. The feeling of 'security' and 'relatedness' can also be improved through the infotainment feature like having a camera view of rear-seat passengers in front-seat passenger cockpit. ‘Stimulation’ is also an obvious expectation from entertainment features. Such potentials can only come true and be enhanced when the infotainment features are executed with appealing interfaces and interactions. For example, it is easy to associate media playing features with stimulation and fun; however, the user interfaces can be *stimulating* as well when they are used to access to *information* features. This argument can be generalized for any interface design, but it becomes even more to-the-point within the scope of this research because ‘passengering’ is less a task or a pragmatic act than driving. In this regard, the interaction aesthetics that are brought by the interaction technologies presented earlier should be elaborated in relation to the expectations from luxury and empowering passenger UX.

2.5 Experience Prototyping with Virtual Reality Simulation

The PhD research aims to investigate the relationship among the qualities of (luxury) experience (*why*) and the varied aspects of front-seat passenger infotainment system interactions (*how* and *what*). Therefore, the previous sections of the literature review deconstructed the user experience with ‘qualities of user experience’ and ‘luxury values’ and presented ‘aspects of aesthetics of interaction’. The literature review also included the front-seat passenger oriented automotive UX research and the technology review of the concept cars. It presented a taxonomy of the new types of functionalities and interactions envisioned for the car infotainment systems with a special focus on the front-seat passengers' travelling experience.

To investigate how our design decisions regarding the interaction aspects of the front-seat passenger infotainment system affect the user experience, interactive demonstrations of the *how* and *what* of the system are needed. Therefore ‘prototype’ or ‘prototyping’ terms constitute a key concept to be elaborated within the literature review.

Accordingly, this section provides the definition of the prototype and prototyping, discusses the role of prototypes in design process, and introduces the types of prototypes. The PhD research utilizes virtual reality (VR) in experience prototyping to gather data about the user experience (UX) of the front-seat passenger infotainment system. Therefore, it also touches upon virtual reality, degrees of reality (e.g. augmented reality (AR) vs virtual reality), key VR concepts, and AR-VR technologies. These are followed by the introduction of the academic research that exemplifies the use of VR in prototyping as part of user/UX studies.

2.5.1 Prototype

Houde and Hill (1997) present prototypes as means of exploring and demonstrating designs (for interactive computer artefacts) and discuss their role as representation of different states of evolving design and exploration of design options.

Similarly, Buchnenau and Suri (2000) and Moggridge (2007) define prototypes as representations of a design made before the creation of final artefacts to inform the design process and design decisions.

2.5.2 Why Do We Use Prototypes?

From the definitions stated above we can identify two main uses of prototypes so far: i) communication of design ideas and ii) exploration of design solutions. However, the “exploration of design solutions” is still a vague statement and it is hard to identify what type of activities-thinking that this exploration involves. There are different approaches in the literature regarding the use of prototypes to explore design solutions. One is identified by Lim et al. (2008) ‘requirement-oriented approaches’ where engineers use prototypes to identify and satisfy requirements. Lim et al. (2008) find this approach limiting for design practices, which are “flexible rather than rigid, reflective rather than prescriptive, and problem setting rather than problem-solving” in their nature. They justify their argument by claiming that “a design that satisfy all the identified requirements does not guarantee that it is the best design since a number of ways can meet each requirement” (ibid., p.2). Therefore, they conceptualize prototypes as “tools for traversing a design space”, in other words, as means of framing, refining and discovering possibilities in a design space.

2.5.3 Types of Prototypes and Dimensions of Prototyping Decisions

2.5.3.1 Types of prototypes based on what they prototype

Houde and Hill (1997) present the model of “what prototypes prototype” so that the designers can use it to deconstruct the design into three dimensions, “which frequently demand different approaches to prototyping”. These three dimensions include ‘role’, ‘look and feel’, and ‘implementation’ (Figure 2.18).

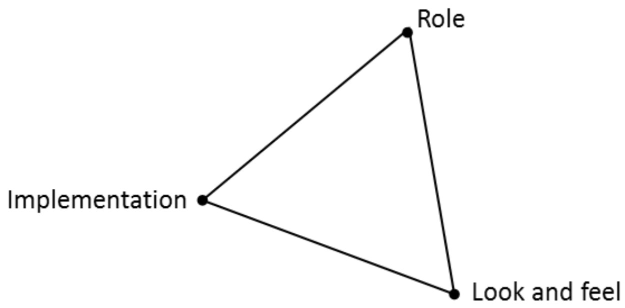


Figure 2.18 The model of what prototypes prototype (Adapted from Houde & Hill, 1997)

‘Role’ refers to the functionality of the product, in other words, how the product becomes useful to people who interact with it. ‘Look and feel’ implies the “concrete sensory experience” of the product, how the product looks, feels at hand, sounds etc. ‘Implementation’ is about the way the product performs its function, e.g. the mechanism, the components, in other words, ‘nuts and bolts’ of the product (Houde & Hill, 1997).

Although Houde & Hill (1997) refer to ‘experience’ while defining ‘look and feel’, its scope is found limited by Buchenau and Suri (2000) who claim that the experience goes beyond the “concrete sensory”. They argue that the experience also includes ‘the role’ (functionalities) and it is under the influence of the contextual factors (e.g. “time pressure, social circumstances”). Therefore, Buchenau and Suri (ibid, p.425) introduce the concept of ‘experience prototyping’ and they define ‘experience prototype’ as

> …any kind of representation, in any medium, that is designed to understand, explore or communicate what it might be like to engage with the product, space or system we are designing.

This holistic approach also applies to the PhD research, which does not confine prototyping into communication of the ‘look and feel’ of the car interior or the infotainment system design itself. It makes use of interaction prototyping to communicate the functionalities and aesthetics of interaction of the front-seat passenger infotainment system within the defined context. This enables gathering data about the user experience of the infotainment system and explore the particularities of the front-seat passengers’ travel experiences.

As mentioned earlier, identification of the varied aspects of the interactive products/systems help designers to elaborate on the specific requirements of each aspect to be prototyped. To exemplify, if a designer would like to explore the ‘implementation’, it would require building or simulating a working system. Prototyping the ‘look and feel’ of the product would require the physical prototypes or simulation that can appeal to a variety of sensory channels. Exploration of the ‘role’ may require the communication of the context of use to investigate usefulness.

Lim et al. (2008) also identify a set of filtering dimensions for prototypes that cover core aspects of design ideas in interactive systems design as shown in Table 2.12.

Table 2.12 Filtering dimensions for prototypes and example variables (Adapted from Lim et al., 2008)

FILTERING DIMENSION	EXAMPLE VARIABLES
Appearance	size; colour; shape; margin; form; weight; texture; proportion; hardness; transparency; gradation; haptic; sound
Data	data size; data type (e.g. number; string; media); data use; privacy type; hierarchy; organization
Functionality	system function; users’ functionality needs
Interactivity	input behaviour; output behaviour; feedback behaviour; information behaviour
Spatial structure	arrangement of interface or information elements; relationship among interface or information elements—which can be either two- or three-dimensional, intangible or tangible, or mixed

If we refer to the three levels of interacting with technology again, we can see that the aspects of (aesthetics of) interaction and interactive products, which are identified in section 2.2.2 "Deconstructing the How: Dimensions of (Aesthetics of) Interaction" (See Figure 2.5 for the literature synthesis diagram) resonate with the role – look & feel – implementation dimensions (Houde & Hill, 1997) and the filtering dimensions (Lim et al., 2008):

The *what* level has been explained with i) the functionality and ii) the content provided by the product, which correspond to the i) 'role' (Houde & Hill, 1997), 'functionality' (Lim et al., 2008) and ii) the data (ibid.). In addition to the *what* level, the how level (interaction) is also referred in Houde and Hill's model (1997) as 'look & feel' and deconstructed as the filtering dimensions of 'appearance', 'interactivity' and 'spatial structure' by Lim et al. (2008). Definition of 'appearance' (Table 12) covers most of the sensory-specific aspects in the literature synthesis diagram (Figure 2.5) that was presented earlier. 'Interactivity' (ibid.) can be easily matched with the 'interactivity aspects that are not specific to a sense" such as action-reaction and temporal aspects. 'Spatial structure' (ibid.), which are presented separately from the 'interactivity' in filtering dimensions was referred as 'spatial aspects' of interaction in the literature synthesis diagram (Figure 2.5).

These dimensions help us about what aspects of the interactive product or system we will or can prototype. However, these dimensions are not enough to decide *how to form* a prototype. In addition to the filtering dimensions, Lim et al. (2018) also mention about other decision items, which they call "manifestation dimensions". These manifestation dimensions -including resolution, material and scope- will be referred as type of prototypes in the following sections.

2.5.3.2 Resolution and/or Fidelity

Lim et al. (2008) define 'resolution' as "level of detail or sophistication of what is manifested in the prototype (corresponding to fidelity)" (p.11). In this definition the terms *resolution* and *fidelity* can be used in place of each other. However, Houde and Hill (1997) define *fidelity* (of a prototype) as "closeness to the eventual design"; whereas they define *resolution* as "amount of detail" (p. 369). Lim et al. (2008) underline that a prototype can be high or low-resolution (fidelity) regardless of its material. For example, a paper prototype of a digital user interface may include rough sketches or detailed visualisation, which would alter its resolution in terms of its appearance. However, if we again refer to the definition of fidelity as 'closeness to the eventual/intended design' (Houde & Hill, 1997), the paper prototype of a digital user interface can be still considered as a low-fidelity prototype in terms of interactivity.

Rudd et al. (1996) explain low-fidelity prototypes based on their limitations to communicate the 'filtering dimensions' such as "limited functionality". Therefore, the design stages utilizing high vs. low fidelity prototypes are different. Because of their limitations, low-fidelity prototypes are built to discuss the design alternatives and explore the early design concepts rather than to model the user's interactions with the system. Rudd et al. (1996) illustrate the low-fidelity prototypes as storyboard presentations and proof-of-concept prototypes.

It is also significant to underline that a prototype does not necessarily have to be either low-fidelity or high-fidelity prototype. McCurdy et al. (2006) introduce "mixed fidelity prototyping approach, which combines low-fidelity and high-fidelity on different dimensions of design considerations" (quoted in Lim et al., 2008, p.5). A 3D prototype of a consumer electronics product can be high-fidelity in terms of communication of the visual or spatial aspects of the design; however, it can be considered as low-fidelity in terms of functionality or interactivity.

2.5.3.3 Material [Medium]

Material is another decision item while forming prototypes and it refers to the "medium used to form a prototype" (Lim et al., p.11). While elaborating on the question of "What is a prototype?", Houde and Hill (1997) discuss the variety of materials that are used in prototypes for diverse design disciplines or activities e.g. the foam models in industrial design or the simulation of on-screen appearance and behaviour in interaction design.

Deciding if the prototype will be *physical or digital (virtual)* can also be considered as a medium-related decision. The use of virtual reality simulation in interaction and experience prototyping will be discussed in detail in following sections.

2.5.3.4 Scope

Lim et al. define 'scope' as "range of what is covered to be manifested" in prototypes (2008, p.11). The scope of the prototype changes depending on what aspect of design we would like to investigate. Lim et al. (2008) exemplify how the scope of a web-site prototype can be limited by using only colour alternatives without text, icons or menus, when the aim is just to decide on the colour-scheme of the web-page. As another example, the scope of a digital user interface prototype can be limited in terms of the information architecture; that is, the prototype does not have to include all navigational steps to demonstrate the main functionality of the interactive system.

2.5.4 Virtual Reality (VR) and VR in Prototyping

In the PhD research, VR simulation is used as means of prototyping front-seat passenger infotainment system. Therefore, the following sections will provide the definitions of the key terms such as VR and virtual prototyping, introduce the main concepts in relation to VR [e.g. immersion, ‘reality-virtuality continuum’, augmented reality (AR)] and related technologies. Then VR in prototyping is discussed through examples from the literature with reference to the scope of the PhD research.

2.5.4.1 Virtual reality, virtual reality vs. mixed reality

VR is defined in Academic Press Dictionary of Science and Technology (Morris, 1992, cited in Wang, 2002, p.232) as:

> a computer simulation of a system, either real or metaphorical, that allows a user to perform operations on a simulated system and shows the effects in real time. e.g., a system for architects might allow the user to “walk” through a proposed building design, displaying how the building would look to someone actually inside it.

As pointed out in section 2.4.3.3, while prototyping products/interactive systems, designers or design researchers can make use of different levels of reality (physicality) and ‘virtuality’ depending on what aspects of design we would like to communicate. Therefore, virtual reality needs to be discussed within “Reality-Virtuality (RV) Continuum” (Milgram et al., 1995; Figure 2.19). RV Continuum ranges from completely real environments to completely virtual environments and anywhere between the two extreme points can be defined as **mixed reality**, which is defined as presentation of real and virtual objects together in a single display (Milgram et al., 1995). The two versions of mixed reality in this RV continuum are **augmented reality** and ‘**augmented virtuality**’ (AV). While in AR physical content is dominating, in AV “some amount of reality” is added to virtual environment. Each type of reality can be created by using different display technologies such as head-mounted displays, tablet screens, and power-wall projections (See Figure 2.19 and Table 13). In some simulation environments ‘mixed reality’ can be approached in a way that physical and virtual objects are not necessarily being seen in the same display, but physical objects-props are used to add physical affordances and constraints to the interaction space as seen in Figure 2.19 on the right.

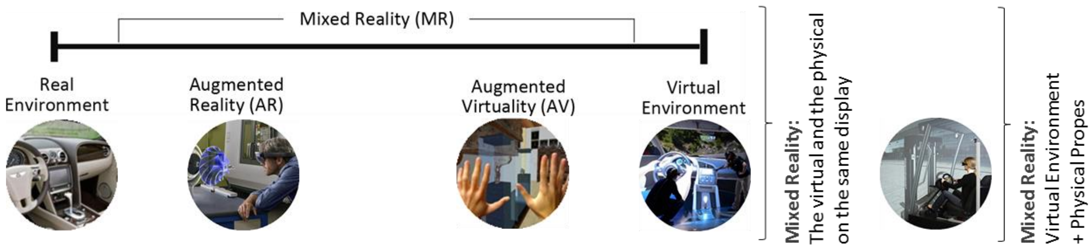


Figure 2.19 Reality-Virtuality (RV) continuum (Adapted from Milgram et al., 1995)

2.5.4.2 Key concepts in VR

Burdea and Coiffet (1994) suggest that there are three key aspects of VR, which are *interaction*, *immersion* and *imagination*. These three interconnected aspects are presented with a model called “the VR triangle” (Figure 2.20).

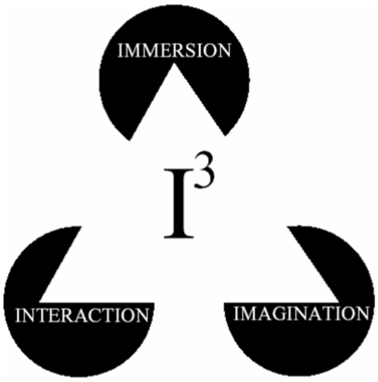


Figure 2.20 VR triangle (Adapted from Burdea & Coiffet, 1994)

Interaction is defined through the capacity of VR system to track the user’s input and to respond to that input with the relevant output (Rebelo et al., 2012). This requires integration of multiple sensory channels (e.g. audio, haptic, visual) based on the type of interaction.

Immersion is defined as “the psychological state of perceiving oneself to be enveloped by, included in a [virtual] environment that provides continuous stream of stimuli and experiences” (Witmer & Singer, 1998, p.227). To achieve immersion in VR/VE, the real (physical) environment should distract the user as little as possible. Gutierrez et al. (2018) identify varied levels of immersion in VR; which are i) *fully immersive* (head-mounted displays); ii) *semi-immersive* (power-wall projections or CAVEs) and *non-immersive* (desktop-based VR).

Imagination refers to the user’s capacity to ‘imagine’ the non-existent things in VR and his or her tendency to believe he/she is in the virtual environment, although he/she is physically situated in another environment.

In addition (and in relation to) these aspects presented in VR triangle, Witmer and Singer (1998) also discuss the concept of "presence" regarding VR experience. *Presence* is defined as "the subjective experience of being in one place or environment, even when one is physically situated in another."

It is argued that to achieve presence, both involvement and immersion are necessary (ibid.). They present the concept of *involvement* as "psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events." (ibid., p. 227). They argue that one can feel involved in other media than VR/VE such as books, videos, games, which are less or non-immersive. However, immersion affects involvement in a positive way and *vice versa*. Therefore, to enable or measure presence in VR, we should address the factors affecting both immersion (being part of the environment) and involvement (attention to the stimuli) together (ibid.).

Witmer and Singer (1998) also present a questionnaire to measure presence in VR. Details of this questionnaire will be touched upon in Section 5.2.4 separately with other measurement tools that are necessary to understand the varied factors affecting the VR experience, therefore the prototyping.

2.5.4.3 Virtual prototypes/prototyping

Wang (2002, p. 233) defines virtual prototype and prototyping as

> … a digital mock-up, is a computer simulation of a physical product that can be presented, analysed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping (VP).

Wang (2002) and Ferrise et al. (2013) both present virtual prototypes as digital substitutes of physical *products* or *prototypes* and they define the act of prototyping as building the prototypes and "testing" them. From their definition it is not very clear what these testing activities involve. However, as a design practice, prototyping should be considered as "framing, refining and discovering possibilities in a design space" (Lim et al., 2008). Therefore, there may be cases where a virtual prototype is used for testing the design proposal against the design criteria that are set earlier, but they can also be used to set the design criteria themselves.

Ferrise et al. (2013) discuss that virtual prototypes are not necessarily interactive, but they should meet the following requirements for whatever aspect of design to be 'tested' (p.158-159):

- "based on functional model for each technical domain"
- "sharable among different stakeholders"
- "modifiable and parametric"
- "context sensitive"

2.5.4.4 Virtual reality/virtual environment vs. virtual prototypes

Wang (1992) claims that there is no clear distinction between the terms virtual reality (VR) and virtual environment (VE), which is the case for Milgram's RV continuum as well. It can be explained with the fact that VR, in definition, implies the 'presence' or 'immersion' (Wang, 1992; Burdea & Coiffet, 1994; Witmer & Singer, 1998) which are 'spatial' in character and suggests being in an 'environment'. Virtual prototypes, however, are not necessarily immersive (Wang, 1992) or interactive (Ferrise et al.,2013).

2.5.4.5 Interactive virtual prototyping

If the virtual prototyping involves investigation of user-product interaction, then the virtual prototype needs to be an 'interactive virtual prototype' (IVP) (Ferrise et al., 2013). The requirements of the interactive virtual prototypes are listed as "realism", "real-time feedback" and "multi-modal and multi-sensory".

Ferrise et al. (2013) differentiate the expectations from virtual prototypes and interactive virtual prototypes and claim that interactive virtual prototypes should be based on:

- "different functional models for each sense and for each external behaviour to analyse and test"
- "parametric for each sense"
- "sharable"

Through use of VR in prototyping we can achieve 'interactive virtual prototyping' of front-seat passenger infotainment system in an *immersive* way.

2.5.4.6 VR-AR simulation technologies

As mentioned in *interaction* aspect of the VR triangle (See Figure 2.20), a VR system should be able to track users' input and refresh the system in a way that it provides a relevant output as a response. This section briefly introduces the variety of technologies enabling such interactivity in VR-AR. It first examines the type of displays used in VR-AR simulations, then it presents the tracking technologies.

a) Displays in VR-AR simulation: Communication of Sensory Modalities

In this section, the term *display* is referred as a piece of equipment, a spatial setting or any form of technology that is used to communicate any sensory modality. Therefore, the displays that will be introduced are not limited to visual displays, but also comprise the technologies that 'display' other sensory modalities such as audio and haptics.

The ***visual displays*** used in VR simulation include a variety of options with different degrees of immersion. These VR displays can be listed as head-mounted VR displays (VR-HMD), power walls and the CAVE applications. Table 2.13 shows different examples of VR-HMD, including the *Vive Pro* headset (VIVE, 2018), which has built-in headphones and a wireless adapter enabling a freedom of movement within the interaction space. Power walls are based on the rear projection of the stereoscopic virtual content to large screens, whereas CAVE (CAVE Automatic Virtual Environment) provides more immersive VR experience by projecting the stereoscopic images to the walls and the floor of the room in a way that the virtual content surrounds the user, who is wearing 3D shutter glasses to view the stereoscopic content (Roy et al., 1992).

There is also a variety of ways to combine the physical and digital objects in a single visual display in AR simulations, including i) head-mounted AR displays (AR-HMD), ii) projection mapping and iii) tablet or smart phone-based AR applications. The head-mounted AR display, *Microsoft HoloLens* is based on holographic computing (Microsoft, 2018). Another AR display, *Magic Leap* uses "digital lightfield' to create the holographic effect, which is explained in the developers' website as "Our lightfield photonics [a lightfield photonic chip in the form of a lens] generate digital light at different depths and blend seamlessly with natural light to produce lifelike digital objects that coexist in the real world." (Magic Leap, Inc, 2018). There is also an AR-HMD example -*AR-Rift*- that is created by the attachment of two cameras to the Oculus Rift VR-HMD to overlay the virtual content onto the camera view of the real environment within the display (Steptoe, 2014). Please refer to Table 2.13 to see the examples for each AR visual display alternatives

Table 2.13 Visual displays for AR-VR simulations

VISUAL DISPLAYS-VR

Head-Mounted VR Displays (VR-HMD)


Oculus-Rift (VR Times, 2017)


HTC-VIVE (The Verge, 2017)


HTC-VIVE pro (Tested, 2018)

Power wall


(Worldviz, n.d)

CAVE


(ART, n.d.)

VISUAL DISPLAYS-AR

Head-Mounted AR Displays (AR-HMD)


HoloLens (Microsoft, 2018)


Magic Leap One (Magic Leap, 2018)


AR-Rift (Steptoe, 2014)

Projection Mapping


(HoloTeQ, 2014)

AR apps for mobile devices


IKEA Place AR app (IKEA, 2017)

Haptic displays are developed to augment the virtual reality interfaces or interactions with the communication of haptic aspects of products and systems. Haptic displays involve i) the wearables (data gloves with haptic feedback or haptic suits), ii) non-wearable HMD controllers with haptic feedback, iii) haptic modelling devices, and iv) mid-air haptics systems. These equipment or systems are based on diverse technologies that provide varied degrees of haptic interaction. They range from the confirmation of the haptic collisions with the virtual content through vibration feedback to the communication of more complex haptic product characteristics such as texture, size, shape, temperature and so on. Most of the data gloves and haptic suits (e.g. *Manus VR Glove*, *bHaptics-Tactsuit, Hardlight VR Suit*) are based on the use of vibration motors (Manus VR, 2017; bHaptics Inc., 2018; NullSpace

VR, 2017); whereas there are also haptic suit examples like *Teslasuit*, which provides haptic feedback through electrical stimulation (Teslasuit, 2018). There are also examples where haptic feedback is provided through vibration motors embedded into inner surface of the head-mounted display like in the example of *bHaptics Tactal VR Mask* (Wired, 2018). Some of the wearable complementary VR equipment with the haptic feedback also make use of pneumatics (use of pressurized air). The examples include projects/products like *Hands Omni* (Wired, 2015) or *HaptX* which is made of microfluid smart textile with an array of pneumatic actuators that push against the user's skin to convey a variety of haptic features including texture (HaptX Inc, 2018). The use of haptic modelling devices in VR simulation is observed in interactive virtual prototyping studies conducted by Bordegoni et al. (2011, 2014), where force feedback capabilities of these devices are utilized to explore the product features e.g. door weight, knob torque of a washing machine. In addition to the haptic systems based on vibration and electrical stimulation, there is also the *Ultrahaptics* mid-air haptics system that use ultrasonic waves to create the feel of products in mid-air (Ultrahaptics, 2018). Please refer to Table 2.14 to see the commercial-academic examples for each haptic display alternatives.

Table 2.14 Haptic displays

HAPTIC DISPLAYS

The wearables

Data Gloves with vibration motors

Manus-VR (Manus-VR, 2017)

Data Gloves with pneaumatic actuators

HaptX Glove (Wired, 2018)

Hands Omni (Road to VR, 2015)

Haptic Suits with vibration feedback

bHaptics-Tactsuit (Engadget, 2017)

bHaptics-Tactal VR Mask (Wired, 2018)

Hardlight VR Suit (NullSpace VR, 2017)

Haptic Suits with electrical stimulation

Teslasuit (Teslasuit, 2018)

Non-wearable HMD controllers with haptic feedback

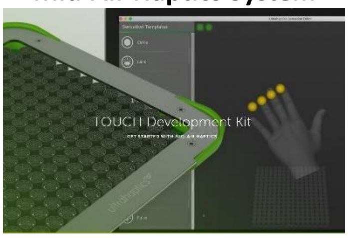
Oculus Touch Controllers (Wired, 2016)

Vive Controller (Reddit, 2017)

Haptic Modelling Devices

(Bordegoni et al., 2011)

Mid-Air Haptics System



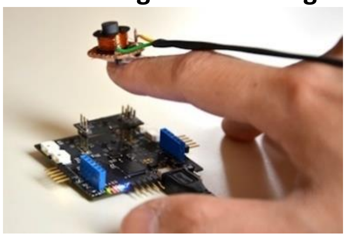
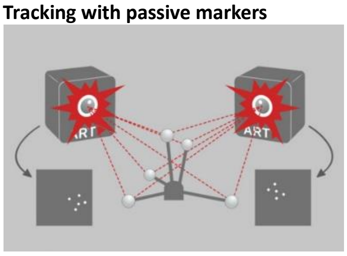
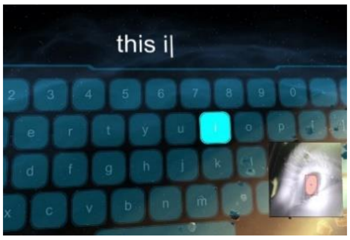
(Ultrahaptics, 2018)

To enable presence in VR-AR simulations ***audio displays*** are expected to provide ***3D audio spatialization,*** which means "the ability to play a sound as if it is positioned at a specific point in three-dimensional space" (Oculus Developers, 2018). The localization of the sound, in other words, the communication of the distance and the direction of the sound source is achieved through the software such as Resonance Audio by Google and Steam Audio.

b) Tracking systems:

Tracking refers to the measurement of position and/or orientation of the bodies (subjects or objects) that move in a defined space (ART, 2018). Through positional or motion tracking, a VR-AR system can monitor the user's input and alters its condition in a way that it produces a relevant feedback to this input. The tracking systems can be either 3 degrees of freedom (3DOF) or 6 degrees of freedom (6DOF). Whilst the 3DOF systems are limited with the measurement of the position along X, Y and Z coordinates, the 6DOF systems are capable of measuring position (3 coordinates) and orientation (3 independent angular coordinates) simultaneously (ART, n.d.).

Table 2.15 Tracking systems for AR-VR simulations

TRACKING SYSTEMS for AR-VR simulations		
Mechanical Tracking		**Ultrasonic Tracking**
 Fakespace Pinch (Stereo 3D, 2006)	 (Bordegoni et al., 2011)	 Ultrasonic sensors (Audiowell, n.d)
Electro-Magnetic Tracking		**Inertial Tracking**
 Finexus Finger Tracker (Chen et al., 2016)	 STEM controller (PC Gamer, 2014)	 Oculus Touch Controllers (Wired, 2016)
Optical Tracking		
Tracking with passive markers		**Tracking with active markers (IR LEDs)**
 Basic tracking principle (ART, 2018)	 (Optitrack, 2018)	 ART Finger tracker (ART, n.d.)
Tracking without markers		
 Leap Motion (Road to VR, 2016)	 **Eye tracking**: FOVE HMD; eye-gaze input & IR camera view (Kickstarter, 2015)	

There are a variety of tracking systems based on diverse position measurement principles and technologies including *electro-magnetic*, *mechanical, ultrasonic*, *inertial* and *optical* tracking (Sherman & Craig, 2003). There are also hybrid systems that combine some these tracking principles (ART, 2018). *Electromagnetic tracking* is based on transmitter to generate a low-level magnetic field and the receivers attached to the user/object. It works in a way that signals in each receiver are measured to determine its position in relation to the transmitter (Sherman & Craig, 2003). *Mechanical tracking* is achieved through rotational and linear measurements of the linkages of the mechanical means that are attached to user's body or handled by the user (Sherman & Craig, 2003). *Ultrasonic tracking* (also referred as *acoustic tracking)* is based on the acoustic signals emitted at timed intervals to determine the distance between the transmitter and the receiver. *Inertial tracking* is about detecting the relative motion of sensors via electromechanical instruments (e.g. accelerometers, gyroscopes) which measure the change in gyroscopic forces, acceleration, and inclination.

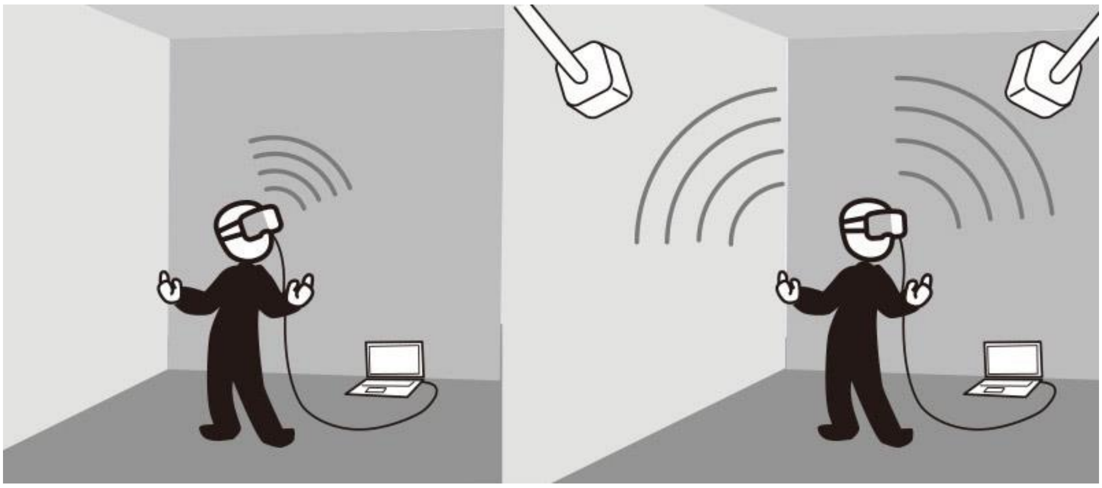


Figure 2.21 Inside-out (on the left) vs. outside-in tracking (on the right) (Acer Inc., 2018)

Optical tracking, which has wide applications in VR industry, makes use of visual information to track the movement of the user/props. The optical tracking system can be either 'outside-in' or 'inside-out' depending on how cameras and optical sensors are positioned with regards to the target in simulation environment (Figure 2.21). In 'outside-in' systems the cameras and optical sensors are placed within the interaction space and oriented towards the user/object being tracked (Dorfmüller-Ulhaas, 2002). On the other hand, in 'inside-out' systems, the cameras are attached to the user/ object being tracked in a way that the system analyses the images of the surroundings to derive the relative position the camera, therefore the position of the user/object (Dorfmüller-Ulhaas, 2002, Sherman & Craig, 2003). The optical tracking can be achieved with or without markers on the objects being tracked. These markers are either light reflectors (passive) of light emitters (active), and they are arranged in a way that the optical sensors can process the light tracked by the cameras to identify and calculate the position and orientation of the markers, hence the position and orientation of the object with the markers (ART, n.d.).

There are also optical tracking technologies that can identify the position of the objects without markers like in the example of *Leap Motion,* the hand tracker equipped with two cameras and three infrared (IR) LEDs. Its software can process the image of the IR-illuminated hands by compensating the background images and reconstruct the 3D representation of the hands (Colgan, 2014).

As mentioned earlier, VR-AR equipment can be based on combination of several tracking systems. For example, HMD controllers e.g. Oculus Touch (see Table 2.15-Inertial Tracking) embody an array of IR-LED markers for optical tracking as well as gyroscopes and accelerometers for inertial tracking.

The target of these position or motion tracking technologies are either the props/objects within the interaction space or the user. Depending on where these trackers are attached and/or the tracking algorithms within the equipment, these systems can provide either full-body tracking or they can specialize in tracking of a specific body part as in the case of hand or finger trackers (e.g. Leap Motion). However, it is also important to mention about eye-tracking/eye-gaze recognition as a version of optical tracking, which is commercialized in HMD applications like FOVE (See Table 2.15-Eye tracking).

2.5.5 Use of VR-AR in Design Research

This research aims to gather data about user experience through VR simulation of front-seat infotainment system. The infotainment systems have been executed as graphical user interfaces; however, interacting with this system within the car interior and possible input (e.g. gestures) and output (e.g. head-up displays) methods for the infotainment system interface require a prototyping tool that can communicate the physical-spatial aspects of the interaction and the environmental context. In other words, communication of the *what* (functionality and content) and *how* (sensory-specific aspects, interactivity aspects) of the front-seat passenger infotainment system and gaining insights about the user experience of this system necessitates a prototyping approach and tools that are different than the ones used to prototype graphical user interfaces (e.g. tablet applications and web-sites). Therefore, this section provides a synthesis of the academic research that demonstrates the use of VR and AR in prototyping within the scope of industrial design and automotive design practices. The review of the related studies involves AR as well as VR, since the methodology and metrics used in design evaluations of AR prototypes are also applicable to VR prototypes.

Rebelo et al. (2012) mentions that due to the limitations of VR in communication of the specific sensory aspects, use of VR in user-product interaction or UX studies is mainly observed at two levels: i) the development of product's external features and ii) functional properties. While the first refers mostly to the perceived quality assessments, the latter is about enabling the users to complete a series of functional tasks without high fidelity communication of interactivity and the context. Methodology-wise, there are again two main approaches, which are applied either separately or together while prototyping with AR-VR. The first approach is about utilization of the modifiable nature of VR (and AR, although it can be less modifiable due to the existence of the physical props) to enable users to make changes or create designs in 'participatory' or 'generative' design development sessions. The second approach is about the integration of usability and UX assessment methods during or after the demonstration of VR-AR prototypes. The following sections will exemplify these approaches as well as introduce the VR processes specifically in automotive industry.

2.5.5.1 Use of VR-AR in participatory design

Bordegoni et al. (2011) create interactive virtual prototypes of washing machines and kitchen cupboards, which include 3D visualization and navigation, interaction visual feedback (e.g. virtual hands in action), haptic and sound models of the components that afford physical interactions (e.g. the drawer, the door, or the knobs) thanks to the use of a power wall, a haptic feedback device and a wireless headset system for sound rendering (Figure 2.22). They first compare the real products and the interactive virtual prototypes based on the perceived effects (e.g. door weight, knob torque, drawer clicks) and find out that the system is promising in terms of realism, although the end effector of the haptic device might feel unnatural to users depending on the physical affordances of the specific component. They also make use of interactive virtual prototypes to define the parameters for the haptic interaction by allowing the participants to modify the effects (e.g. louder click sound while rotating the knob). They argue that these parameters play a significant role in creating the first impression of the products that customers have when interacting with them. Therefore, the study constitutes a good example for the use of VR and haptic systems for generative perceived quality modifications in product development.

Figure 2.22 The set-up (Bordegoni et al., 2011)

Bordegoni and Caruso (2012) present the potentials of mixed reality platforms for *collaborative design review of automotive interior* by different parties including designers, final users and engineers. The mixed reality environment (Figure 2.23) in this study consists of a seating buck structure, optical see-through head-mounted display (OST-HMD), which enables user to see the virtual interior and the test environment at the same time; a robotic arm to make necessary changes in the place of particular dashboard components such as knobs and buttons; and an optical tracking system to track user's movements. This collaborative review works in a way that users in mixed reality platform demand some changes regarding the interior; designers simultaneously respond to these changes in virtual environment by altering the 3D virtual model, which is transferred to the HMD that the user is wearing and this change is also physically realized by the robotic arm (Bordegoni & Caruso, 2012).

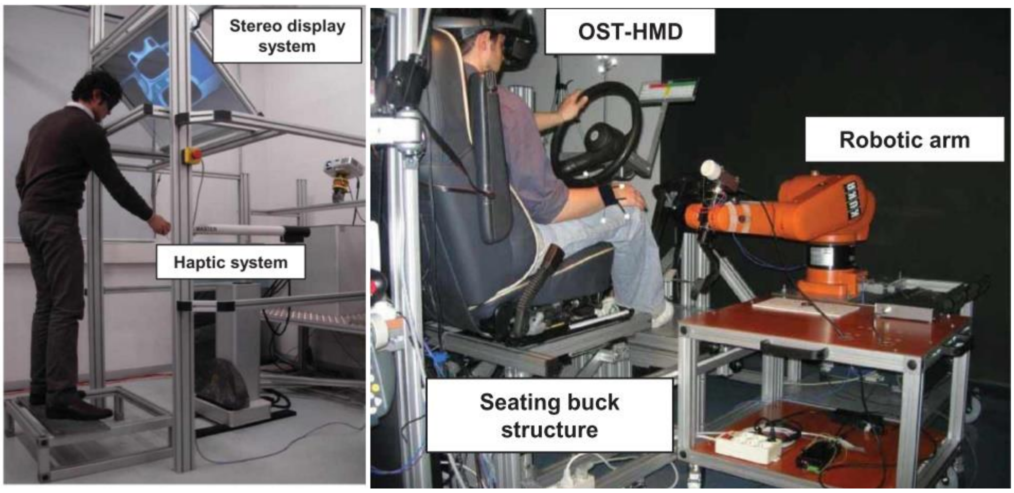


Figure 2.23 Virtual design environment with a haptic modeler and the mixed reality test environment (Bordegoni and Caruso, 2012)

Bruno and Muzzupappa (2010) also introduce a system called VP4PaD (Virtual Prototyping for Participatory Design), which enables users to compose a functioning product interface by using the available functional components e.g. buttons, switches or handles. The modifiable nature of the virtual prototype helps users to go through design iterations and allow quick usability assessments based on the number of errors and task completion times. The results point out that users performed better with revised designs compared to the commercial interface provided.

2.5.5.2 Usability and user experience evaluations

The study on the collaborative design review of automotive interior via mixed reality platforms (Bordegoni & Caruso, 2012) also involves measurement of the usability of the mixed reality seating buck based on the criteria set by Nielsen (1994). They measure the *learnability*, *efficiency, margin of system and user errors* and the overall *satisfaction* by referring to the recording of the users' performances and comments during the sessions and their answers to a questionnaire.

The objective measurement of user's interactions can be more complex than measuring the number of errors and the task completion time. Aoyama and Kimishima (2009) utilize augmented reality prototypes of digital camera and a cell-phone (with buttons) equipped with motion sensors and data gloves to detect and analyse users' manipulations (Figure 2.24). Through mixed reality, physical models are used to communicate the tangible interactions in the most realistic way, whereas graphical user interface is dynamically overlaid onto the physical model through head-mounted displays. Thanks to the data gloves and magnetic sensors, the system is able to detect finger angles and hand motions, which can produce data such as 'sum of changes of all finger bending angles between pushing buttons'that helps measuring the 'operability' of the design.

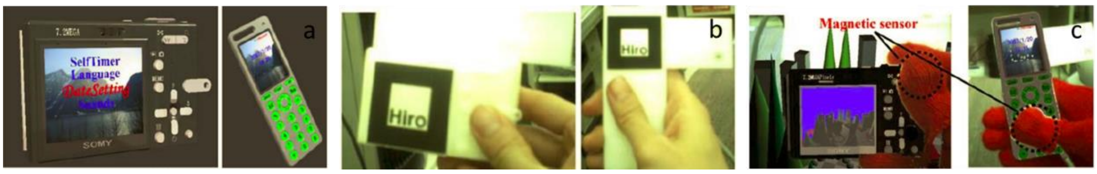


Figure 2.24 The virtual (a), physical (b) and hybrid/mixed reality (c) models (Adapted from Aoyama and Kimishima, 2009)

Similarly, Zhang and Mi Choi (2013) present tangible augmented reality as a method to evaluate the usability of products. This method involves a physical artefact equipped with controls (buttons), able to record users' button use and an augmented reality view attached to the artefact.

Bordegoni et al. (2014) propose a methodology which can be given as an example to the limited number of studies that deal with user experience evaluation with use of VR that goes beyond the usability assessments. As part of a preliminary experiment, they present the user an interactive virtual prototype of a refrigerator with a few adjustable configurations for the way its door closes (e.g. required force, click effect). After modifying the parameters and reaching a satisfactory effect for each configuration, the user is asked to fill in ‘a self-assessment manikin (SAM)’ to express his/her feelings. SAM is “a non-verbal pictorial assessment technique that directly measures the pleasure, arousal, and dominance associated with a person’s affective reaction to a wide variety of stimuli” (Bradley & Lang, 1994). Bordegoni et al. (2014) discuss that the method is promising to set a correlation among the physical characteristics of virtual prototypes with specific emotional reactions, if such study is conducted with statistically acceptable number of participants.

2.5.5.3 VR Processes in the automotive industry

According the Lawson et al. (2015) the main VR applications in automotive industry include: “*manufacturing workstation optimization*; *vehicle design*; and *assembly training*”. Based on the interviews with eleven Jaguar - Land Rover (JLR) employees with expertise or interest in VR, Lawson et al. (2015) make a critical review of VR processes used in automotive industry by giving information about: i) the commonly used physical and virtual prototyping methods, ii) which one is used to assess what aspects of products (e.g. physical prototypes for assessing user's movements such as reach and clearance and VR for assessing vehicles architecture), iii) users of each methods, and iv) the issues related with each method (e.g. time spent for the production of physical prototypes or lack of haptic feedback in VR systems). The review also includes the recommendations for the VR related issues. For example, one issue concerning the VR was mentioned as the need of realistic simulation of the sound in switch operation, assembly ergonomics and vehicle noise. The recommendation provided is using a 3D sound system (ibid., 2015).

Lawson et al. (2015) discuss that the VR speed up the iterative vehicle design processes by replacing the physical prototypes which requires to be rebuilt again and again during design reviews. Another advantage of using VR is presented as facilitation of the collaboration among the product development teams from different disciplines and/or locations, which has also been mentioned by Ferrise et al. (2012) as one of the virtual prototype criteria: *sharable among stakeholders.*

It is important to note that what is referred as vehicle design in Lawson et al. (2015) is the vehicle interior-exterior design without specific emphasis on automotive user interfaces or automotive HMI. The only example that gives a hint about the use of the VR as part of user studies is 'ergonomic evaluations', in addition to the driver distraction assessments and assembly trainings, which eventually require trainees.

Ihemedu-Steinke et al. (2017) also explore the use of the VR in automotive industry and list its application areas as "*vehicle designing, immersive virtual driving tests, marketing and sales, collaborative engineering,* and *evaluation of concept and performance targets".* They also present a table (Table 2.16), which shows application areas of the VR within a selection of automotive manufacturers.

Table 2.16 Application areas of VR within a selection of automotive manufacturers
(Adapted from Ihemedu-Steinke et al., 2017, p.409)

Manufacturer	**Application area**	**Benefits**
Audi	Customer vehicle configuration	- Enhanced user experience - Virtual showroom, saves space
BMW	Vehicle development-virtual prototype and car designing	Fast prototyping saves time and costs
Chevrolet	Advertisement and sales	Virtual showroom, immersive driving experience
Fiat Chrysler	Advertisement and Sales	Explore a car before it is built
Ford Motor	- Vehicle interior and exterior design - Autonomous vehicle technology	- Design better and safer cars - Rapid prototyping
Lexus	Virtual prototyping	Test cars before they are built
Mercedes Benz	Virtual test drive—Marketing	Test cars before they are released
Nissan	Virtual test drive	Product awareness
Porsche	Customer entertainment	Product awareness
Renault	Research and development	Saves time and costs
Toyota	Driver distraction campaign	Creates awareness to safe driving
Volvo	Virtual test drive—Marketing	Product awareness

The studies conducted by Ihemedu-Steinke et al. (2017), Jeong et al. (2013) and Weir (2010) present the VR driving simulators as part of the investigation of the effects of secondary (HMI) tasks on the driving performance and evaluation of HMI interactions from the usability perspective (e.g. input error rates, glance behaviour, task time). On the other hand, Alvarez et al. (2017) present Intel Labs' Skyline, which is a prototyping platform to be used in design, implementation and evaluation of in-vehicle concept experiences. It can be considered as a driving simulator with all physical components (e.g. display, steering wheel, and seating bucks) empowered by the open-source platform and assets to create specific driving simulator environments and interaction scenarios. It offers a virtual library including static images and audio files to be used as part of the user interface-car HMI. However, in this simulation tool, the level of interaction with HMI is limited to the use of 'Wizard of Oz' (WOZ) prototyping method. "When prototyping with WOZ, one or more 'wizards' simulate part or whole of the performance of the system being designed, while interacting with users who preferably believe themselves to be using a real system" (Bernsen et al., 1994, p.1). The method is used to communicate an interface idea without identifying the underlying technology and creating a working interactive prototype (Dow et al., 2005). To do so, the input to and output from the system need to be mimicked by the researcher to create the illusion of a working system. This method may communicate how the system will be used but falls short of exploring specific aspects of aesthetics of interaction (e.g. response time) that cannot be communicated in the same manner with the programmed interactions.

We can draw the conclusion that the potentials of the VR are not adequately explored for the investigation of the user experience of automotive HMI. The studies that utilize the VR for HMI appraisals focus on the usability of these systems. They handle HMI interactions as tasks to complete, rather than as potential means of a pleasant or luxury experience.

2.5.6 Advantages and Disadvantages of Using VR in User Studies

Rebelo et al. (2012) group the advantages of using VR for user experience research into three main topics: *availability*, *safety,* and *data provision*:

What is meant by *availability* is to be able to simulate specific context in a repeatable and systematic manner without spending the time and cost required by the real/physical set-ups. Rebelo et al. (2012) also argue that availability encourages the participation of people with disabilities to user studies. Use of the VR also eliminates most of the *safety* risks that would be posed by the real/physical set-ups. This can be illustrated by driving simulators that enable the participants to drive in all sorts of road conditions without being injured in case an accident occurs. Safety is not only about prevention of injuries; the VR also enables practices through trials and errors without being literally affected by their social-practical consequences. This creates a margin for the misuse of product interfaces and encourages the participants to explore the VR prototypes without worrying about breaking the system. Another advantage of using VR in user studies is presented as *data provision*, since it helps design researchers to collect data even in the initial stages of design process confirming "high accuracy and good ecological validity", which is quite unlikely in real-life settings.

Regardless of the technology-based limitations of the VR prototypes to communicate specific sensory aspects of (interactive) products or systems (e.g. tactile-haptic aspects), the main drawback of using the VR as part of user studies is presented as simulation or *simulator sickness (SS)* (Rebelo et al., 2012). A clear definition of simulator sickness is provided in Oculus Developers web-site (2017) as "a form of induced motion sickness that results from the conflicts between the visual and bodily senses". Although it is presented as a form of induced motion sickness because of the common symptoms, it is differentiated from motion sickness by Kennedy et al. (1993, p.203), since "simulation sickness tends to be less severe, to be of lower incidence and to originate from visual display and visuo-vestibular interaction atypical of conditions that induce motion sickness." The simulation sickness may include symptoms like eyestrain, nausea, dizziness etc. (ibid.).

Rebelo et al. (2012) argues that the SS symptoms may be due to a variety of factors. Simulation sickness can result from the *technological issues* such as delays in feedback to user's input. It is also observed that as the Virtual Environment (VE) becomes more immersive (e.g. head-mounted displays) simulator sickness may increase (Rebelo et al., 2012) due to high sensory conflict. Another factor affecting the simulator sickness can be the way the *VR system and interactions* are designed. To exemplify, Stanney and Hash (1998) and Sharples et al. (2008) argue that simulator sickness decreases when participants are given more control over the system or when they are more active than passive in VE (cited in Rebelo et al., 2012). Regarding the system design the visual complexity of the VR scene and the long duration of the VR simulation can induce SS symptoms more. Simulation sickness is also claimed to be based on the individual differences such as *age* (different susceptibility in different age groups), *gender* (females are found to be more susceptible) and *the motion sickness susceptibility* (based on the varied sensibilities and health conditions) (ibid.).

Kennedy et al. (1993) present a *simulator sickness questionnaire (SSQ)* (Appendix 2), which includes a list of symptoms to be rated in terms of their severity with a four-point Likert scale. These symptoms influence the effectiveness of the VR simulation as well as the health and safety of the participants. Therefore, it is important to measure the existence of these symptoms before and after the VR demonstrations to understand, if the simulation cause any sickness that might play a role in participants' performances or design evaluations.

2.6 Conclusions

Chapter 2. "Literature Review" included four main strands; namely i) dimensions of user experience and user-product interactions (Section 2.2), ii) concept of luxury and luxury values (Section 2.3), iii) contemporary automotive infotainment solutions to empower front-seat passengers (Section 2.4), and iv) experience prototyping with VR simulation (Section 2.5). The conclusions for each or combination of these strands are provided below:

- Infotainment systems are parts of the car interior and as presented in Section 2.4, with integration of embodied interaction technologies, they are becoming more multi-modal and more multi-dimensional than graphical user interfaces. This requires a comprehensive list of aspects to describe users' interactions with these systems (*how*). Therefore, the aspects of interactive products (how and what) are collected from the literature and synthesized in a way that the categories involve sensory-specific aspects (e.g. tactile aspects) as well as other interactivity attributes that are not specific to a sensory modality (e.g. temporal aspects). Another conclusion was that the relationship among the existing categories (e.g. spatial vs. action-reaction) that deconstruct interactions was not reflected into any model/framework in the aesthetics of interaction literature. In addition to the sources referred, the diagram that visualizes the synthesis (See Figure 2.5) of these sources also reveals that execution of presentation or action-reaction related decisions are based on the design decisions regarding dynamic/static sensory aspects of interaction (sensory, spatial, temporal aspects) or *vice versa.*

- Aesthetics of interaction-related design decisions do not necessarily depend on the technologies used in the infotainment system, nevertheless, every interaction technology presented in Section 2.4 comes with its own interaction aesthetics. This research will refer to the aspects of interaction revealed through the literature review to discuss the simulation challenges of a selection of these interaction technologies. These technologies will then be utilized in design of the controls and displays of the front-seat passenger infotainment system.

- The filtering dimensions (What to prototype?) identified by Lim et al. (2008) in Section 2.5 can be enriched again with the use of the aspects of interactive product and interactions (*how-what*), while deciding what to prototype within the front-seat passenger infotainment system, so that the scope, medium and fidelity of the prototype can be defined to be able to communicate these aspects to users

- The literature review on the qualities of experience showed that there are plenty of studies that present the basic dimensions of a pleasant experience through pragmatic-hedonic qualities of UX (Hassenzahl, 2003); human needs (Sheldon et.al., 2001) and pleasures (Jordan, 2000). However, when it comes to creating metrics to describe and quantify the user experience of the interactive systems, the existing sources don't cover the hedonic qualities/needs/pleasures as much as the pragmatic ones (usability and usefulness). In this regard, AttrakDiff questionnaire (Hassenzahl et al., 2003) emerged as a comprehensive UX evaluation method that identifies semantic differentials for both hedonic and pragmatic qualities of experience. It is expected that still there will be some needs/qualities that are relevant for the front-seat passengers' expectations from the infotainment system, but not yet covered in the questionnaire. In this research, these expectations are aimed to be investigated further through the user study.

- The collaboration with the Bentley Motors also necessitates identification of dimensions of luxury experience, which is not explored thoroughly in UX literature, where luxury is only defined through ownership of expensive products. In this regard, Section 2.3 "Concept of Luxury and Luxury Values" revealed that all luxury values presented in marketing literature highly correspond to the qualities of experience/metrics presented in Section 2.2 (Please refer to Table 2.4 to review the corresponding terminology). However, differentiating the luxury experience from a pleasant experience is still a difficult task. This points out a need for a user study where we can investigate which qualities of pleasant experience are more relevant for the infotainment systems of luxury cars, if there are other qualities that define luxury, and find out through which aspects of interactions and functionalities a luxury infotainment system can be achieved.

- The concept car examples presented in the technology review in Section 2.4 show that passenger empowerment is on the agenda of automotive companies. This empowerment has been achieved either through exclusive solutions like infotainment screens dedicated to front-seat passenger or active involvement of front-seat passengers in the use of the infotainment system. The categorizations provided in Table 2.6 can be considered by designers and design researchers as a selection of approaches to follow while addressing the front-seat passengers' needs. However, most of the solutions demonstrated in that section fall short of making use of the full potential of the available interaction technologies. Despite the new infotainment features/functionalities provided, the general approach pursues a selective duplication of previous driver-oriented solutions. We generally observe screens attached or extended to the passenger dashboard together with gesture or touch-based controls, although the solutions can be more flexible, such as portable displays and controls, and head-up displays as part of information provision, entertainment or communication. In fact, a technology, which has been used for pragmatic purposes for the driver can deliver hedonic quality to the front-seat passenger's user experience.

- Front-seat passenger-specific infotainment has not been explored enough in production cars until now. Further investigation is needed to understand which solutions offered by the R&D efforts would be more favourable and worthwhile when applied into a real car. The relevance of the solutions needs to be tested with due consideration of different travel scenarios or contexts.

- The technology review of the concept cars also showed that the link among the *why-what-how* dimensions of the front-seat passenger experience is also missing. The solutions demonstrate the most recent technologies and functionalities, but the motivations behind these front-seat passenger-oriented applications are not always clear. In other words, there is not enough exploration on how these solutions will enhance the user-experience or deliver hedonic and pragmatic quality. Therefore, while testing the design proposals, the research should be conducted in a way that we can investigate the links among different dimensions of the front-seat passenger infotainment experience, which constitutes the main objective of this PhD.

- The literature review presented in Section 2.5 showed that there is a list of decision items (e.g. what to prototype, scope, medium, fidelity) to be referred while prototyping the front-seat passenger infotainment system. It also presented the degrees of reality (AR-VR) and the simulation technologies to be considered while deciding on the medium of the prototype. Chapter 3. "Methodology" and Chapter

4. “Design and Simulation of the Front-Seat Passenger Infotainment System” will investigate the studies that facilitate the prototyping-related decisions further in detail. However, the role of virtual reality in this research can be explained with the fact that experience prototyping of an interactive system demands the interactive communication of the functionalities and aesthetics of interaction of the system within the defined context. The front-seat passenger infotainment system, as an in-car interactive system, has action-reaction or temporal aspects, which need to be digital/programmed, and spatial aspects where immersion will be useful. Therefore, the prototyping tool requires a certain degree of “virtuality”.

- Section 2.5 also revealed that use of VR for prototyping user experience and as part of a user study calls for an evaluation of how being in a virtual environment affects users. This points out the necessity of measuring presence and simulation sickness in VR simulation to be able to confirm that participants felt well and present enough to reflect on the design proposal.

- Finally, with regards to the aim and objectives of the PhD research, there are two main research gaps identified in Section 2.5. First one is the lack of adequate number studies using interactive virtual prototypes and/or VR as means of UX research that go beyond usability evaluations. The second one is the underexplored potentials of immersive and interactive virtual environments to prototype automotive user interfaces. Since the PhD research will handle the infotainment system interactions as the primary task for the front-seat passenger, the exploration needs to be more complex and varied than the driver-automotive HMI interactions, which have been approached as the secondary task affecting the driving performance.

The following chapters will first present the methodology of the research. This will be ensued by development of a front-seat passenger infotainment system design and the VR simulation where the functionalities and interactions of the system will be experienced as part of a travel scenario. This will be followed by the presentation the results of the user study where participants will evaluate their infotainment experiences with the metrics defined in literature review and provide further suggestions and concerns about the infotainment system.

CHAPTER 3.

METHODOLOGY

3.1 Introduction

This chapter presents the overview of the main phases of the PhD research by introducing the theoretical framework and methods that are employed in each phase. It discusses how findings of the literature review are synthesized to support the design and simulation of the front-seat passenger infotainment system, and how design and simulation will be used as a means of data collection in order to investigate the relations among the qualities of luxury user experience and the front-seat passenger infotainment system aspects.

Therefore, this chapter first introduces the role of design and simulation in the PhD research which follows ‘research through design’ approach. It provides the definitions of several methodological approaches that explore the relationship between research and design practice and posit the PhD research within these approaches. Then, the chapter presents the main phases of the PhD research aiming at answering the research questions. By doing so, it provides a basis for a more detailed articulation of the methods utilized in each phase which will be individually introduced in the dedicated sections of the following chapter entitled ‘Design and Simulation of the Front-Seat Passenger Infotainment System’.

Diagrammatic explanation of the PhD phases and their relations can be seen in Figure 3.1. The figure explains the following information:

- **Literature Review** of
    - Dimensions of user experience and user product interactions
    - Concept of luxury and luxury values
    - Contemporary automotive infotainment solutions to empower front-seat passengers
    - Experience prototyping with VR

- **Design and Simulation of the Front-Seat Passenger Infotainment System**
    - Focus group: exploration of the simulation challenges of interaction technologies (with the VEC)
    - Concept development of the front-seat passenger infotainment system

- Design detailing and simulation development
- Experience prototyping of the front-seat passenger infotainment system through VR simulation

- **Analysis of the experience prototyping of the front-seat passenger infotainment system through VR simulation** to inform future front-seat passenger infotainment system designs.

3.2 Research & Design (& Simulation)

This section will introduce the 'research through design' approach and justify why the PhD is positioned within this approach.

While discussing the relations between research and design and how these practices contribute to each other, Stappers and Giaccardi (2018) first differentiate the connotations that have been assigned to the terms research and design. In this context, the purpose of research is defined as 'production of knowledge, whereas the purpose of design is defined as 'creation of a specific solution'. Regarding how these two (different) practices relate to one another, the categories presented by Frayling in 1993 constitute a significant reference for HCI (human-computer interaction) or interaction design literature (Zimmerman et al., 2010; Gaver, 2012; Stappers & Giaccardi, 2018), which are: i) 'research about design', ii) 'research for design', and iii) 'research through design'. Archer (1995) also introduces his three-part model of research i) into practice, ii) for practice and iii) through practice based on his earlier studies on the 'action research' where he first mentions about the 'research through practice' approach.

> **Research about Design** refers to the research about the design processes and theories. Frayling (1993) exemplifies this type of research with "historical research, aesthetic or perceptual research, and research into a variety of theoretical perspectives on art and design" (p.5).
>
> **Research for Design** implies "improving the design practice" through the research activities of "observation, measurement, interview, literature review, analysis, and validation" (Stappers & Giaccardi, 2018, 43.1.2) and the expected outcomes of this type of research are illustrated as "frameworks, philosophies, design recommendations, design methods, and design implications" (Zimmerman et al., 2010; p. 313).

Research through Design is defined as "a research approach that employs methods and processes from design practice as a legitimate method of inquiry" (ibid., p. 310). In this type of research, design activities including *prototyping*, play a significant role in both generating and communicating knowledge (Stappers & Giaccardi, 2018). In his paper 'The Nature of Research', Archer (1995) discusses 'research activity that is carried out through the medium of practitioner activity' in other words, 'research through practice' with the following:

> There are circumstances where the best or only way to shed light on a proposition, a principle, a material, a process or a function is to attempt to construct something, or to enact something, calculated to explore, embody or test it. (p. 11)

Investigation of the relations among the qualities of luxury user experience and the front-seat passenger infotainment system aspects also requires a representation of the system, so that the users can comment on the system and the values it would bring to their car journeys. Therefore, as stated in the definition of the research through design/practice, the research will employ a front-seat passenger infotainment system proposal as a method of enquiry. The communication of the proposal to the users will be achieved through VR simulation. Whilst discussing the term research through design, Zimmerman and his colleagues (2007) underline that the main intention behind developing a design/prototype as part of design research is to produce knowledge and not to create a solution or have an immediate contribution to the development of a commercial product. This approach applies to this PhD research as well.

Therefore, if we refer to these three categories of design research, the PhD can be positioned within the 'research through design (for design)' approach since it includes;

- structuring of the findings from the literature review to guide the design and prototyping processes conducted as part of a research activity;

- the use of design prototype (experience prototyping with VR) in both evaluative and generative ways by applying mixed research methods (e.g. semantic differential scales, semi-structured interviews) for research participants to reflect on the design prototype;

- the analysis of the user studies (experience prototyping with VR) to inform the future front-seat passenger infotainment system designs through: i) investigation of the contributions of the proposed infotainment features (*what* level) and aesthetics of interactions (*how* level) to luxury user experience (*why* level), ii) identification of the specific qualities of user experience that define the front-seat passenger's expectations from a luxury infotainment system, iii) categorisation of the solution spaces informed by participant's suggestions to improve/enrich the design proposal and their underlying motivations, iv) creation of a framework to conceptualize the front-seat passenger's changing roles and relations with the infotainment system to tackle their changing motivations, and v) creation of a bullet list of design considerations, which summarizes the main findings of the analysis in a way that would benefit the designers of the future front-seat passenger-oriented infotainment systems.

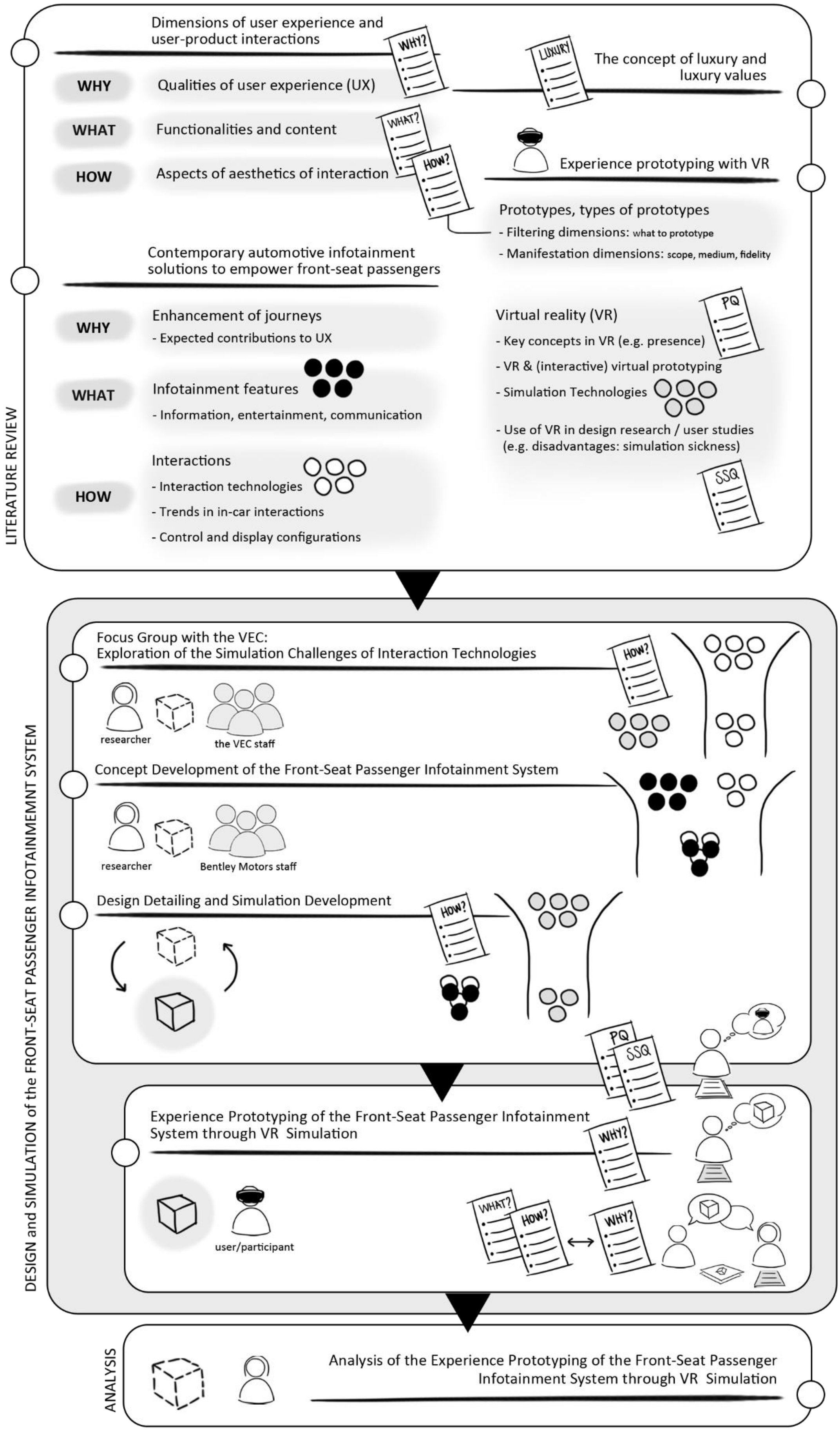


Figure 3.1 Main phases of the PhD research

3.3 Main Phases of the PHD

Referring to Figure 3.1, this section introduces the main phases of the PhD research and discusses how they contribute to each other. It first gives a summary of the findings of the literature review to explain how these findings will contribute to the methods that will applied in the following phases of the research. Then it briefly introduces the consecutive phases within design and simulation of the front-seat passenger infotainment system and the analysis of the experience prototyping.

3.3.1 Literature Review

The literature review was carried out in order to support the answers to the research questions as described in the following.

The first research question of the PhD research was: "RQ1. *How can the qualities of luxury user experience be manifested via different aspects of front-seat passenger infotainment systems?".* To answer this question, a couple of supporting questions were needed to deconstruct the problem area. These were:

- RQ2. *What metrics define a pleasant user experience; how does the concept of luxury relate to these metrics?*
- RQ4. *When the front-seat passenger infotainment system is considered as an interactive system, how can user interactions with the system be deconstructed into separate elements?*

As pointed out in the supporting research questions, the development of infotainment system solutions to improve the quality of front-seat passenger's travel experience in a luxury car required deconstruction of both users' expectations from the infotainment experience and the solutions answering these expectations. In this regard, the present research referred to the framework of *why, what* and *how* levels of interacting with technology (Hassenzahl, 2010). Figure 3.1 demonstrates:

- Deconstruction of these levels as qualities of experience (*why*), functionalities and content (*what*), and aspects of aesthetics of interaction (*how*); synthesis of marketing and UX literature to discuss luxury values in relation to the qualities of experience and semantic differential pairs that were used as UX evaluation metrics in experience prototyping

- Categorisation of contemporary automotive infotainment solutions to empower front-seat passengers based on *why*, *what* (directions for the infotainment features/functionalities) and *how* (interaction technologies that are expected to change the way we interact with automotive HMI) levels to facilitate the design and simulation phases of the research that also aim at answering RQ5.

- Elaboration on 'experience prototyping with VR' to answer RQ6. "*How can simulation technologies be used to explore front-seat passenger infotainment concepts; what are the specifications of the experience prototyping tool-methodology to appraise the user experience of front-seat passenger infotainment system?",* decision to use the *what* (functionality, content) and *how* aspects of the interactive product (aesthetics of interaction) as new 'filtering dimensions', decision on diverse simulation assessments to be made in experience prototyping study, such as presence and simulation sickness questionnaires.

3.3.2 Design and Simulation of the Front-Seat Passenger Infotainment System

3.3.2.1 Focus Group: Exploration of Simulation Challenges of Interaction Technologies (with the VEC)

The VEC was the research partner which has been involved in all simulation-related decisions. Therefore, a focus group with the VEC staff was conducted to collectively discuss and shortlist the interaction technologies presented in Section 2.4, to be further considered as part of front-seat passenger infotainment system design. In this shortlisting process the focus group participants were encouraged to refer to the aspects of interaction (*how*) while discussing whether a specific interaction technology could be prototyped with VR or not (See Figure 3.1). The list of simulation technologies derived from the literature review was referred in the discussions of possible medium/media which can be used to prototype the interactions offered by a specific technology. This study integrated the research through design approach by presenting the participants the initial ideas generated for the infotainment system. This was expected to help them imagine what needs to be communicated through simulation.

This study constituted a background for the simulation development and enabled taking prototyping decisions (e.g. what to prototype, scope, fidelity, medium) within the limitations of the simulation capabilities of the VEC. Therefore, it can be regarded as the first practical step in answering the RQ6.

3.3.2.2 Concept Development of the Front-Seat Passenger Infotainment System

Concept development of the front-seat passenger infotainment system included devising new functionalities (infotainment features) as part of a travel scenario with reference to the qualities of luxury user experience (*why* level dimensions) and the explorative nature of the Bentley Continental GT travels. This phase of the research also involved preparation of the design proposals for the control and display alternatives of the front-seat passenger infotainment system. These alternatives were based on the interaction technologies that had been shortlisted in the focus group. Regarding the functionalities, the new infotainment features were developed with reference the categories for the infotainment features (information, entertainment, communication) presented in the literature review (See Figure 3.1). This phase can be considered as the design response to the above-mentioned research question of the RQ5.

The design proposals (new infotainment features, control and display alternatives to deliver each infotainment feature in varied ways) were presented to Bentley Motors HMI design team. Based on their review of the design proposals, the functionalities were revised in a way that they would better fit to a Bentley Continental GT travel scenario, then the final control and display alternatives were decided.

3.3.2.3 Design Detailing and Simulation Development

This part of the research included the decision process about what to prototype and definition of the scope, medium and fidelity of the prototype, since they affected the way the aspects of aesthetics of interaction, the functionalities, content and the context of travel / interactions were communicated. Figure 3.1 demonstrates the selection of the medium of the prototype out of a variety of simulation technologies that were available in the VEC. This selection was based on the design proposal which was revised after the review of the Bentley Motors HMI design team.

The simulation development involved two main tasks: visualisation, and programming. The two tasks can also be considered as parts of design detailing. Most of the design decisions regarding the aesthetics of interaction were planned to be revised in an iterative way as the interactions were programmed and experienced during the simulation development process. This iterative process is also demonstrated in Figure 3.1.

3.3.2.4 Experience Prototyping of the Front-Seat Passenger Infotainment System through VR simulation

The phases / studies that have been mentioned earlier can be considered as the backbone of this study. It involved VR demonstration of the front-seat passenger system, user experience evaluation, and simulation evaluation. The details regarding the data collection methods and protocol of the study will be mentioned in detail in the following chapters. However, this section will offer an overview of experience prototyping to explain how each step of the study is built on the findings of the literature review.

It is important to mention what is meant by VR demonstration of the front-seat passenger system: it is the simulation of the new infotainment functionalities and interactions in a travel scenario within a virtual environment, which includes the car interior, controls and displays of the infotainment system and the surroundings images.

Although it did not constitute the main objective of the research, the VR simulation itself was evaluated as a tool regarding its possibility to cause simulation sickness (via simulation sickness questionnaire – SSQ) as well as its provision of the sense of presence; more specifically realism (via presence questionnaire). The latter was to understand if the participants were able to imagine using such infotainment system in a real context, so that user experience-related data collected from the research participants could be considered reliable.

Reflection on the user experience started with the use of UX evaluation questionnaire, a Likert scale including semantic differential pairs that correspond to varied qualities of (luxury) user experience that are mentioned as part of *why* dimension in Chapter 2. The reflections on the user experience continued with a semi-structured interview to investigate how a specific quality of user experience / luxury value was associated with a specific aspect of interaction aesthetics or a specific functionality; in other words, to investigate the links among *why, what and how* of the front-seat passenger infotainment system. The interview also included a discussion of challenges that participants experienced and the potential areas of enrichment and improvement in the design proposal.

3.3.3 Analysis of the Experience Prototyping of the Front-Seat Passenger Infotainment System through VR simulation

This phase of the PhD research involved the analysis of the data collected through experience prototyping of the front-seat passenger infotainment system with VR simulation.

This phase included the statistical analysis of the simulation sickness, presence (realism) questionnaires as part of the evaluation of the VR simulation as well as the user experience evaluation questionnaire. Nevertheless, the main data of the user study were taken from the semi-structured interview that followed the VR simulation. The interview transcripts underwent a content analysis, findings of which constituted a comprehensive response to the research questions of RQ1 and RQ3. (See Section 3.2 to review the expected findings of the experience prototyping study).

CHAPTER 4.

DESIGN AND SIMULATION OF THE FRONT-SEAT PASSENGER INFOTAINMENT SYSTEM

4.1 Introduction

This chapter presents the details of the four main phases of the design and simulation of the front-seat passenger infotainment system. These phases are: i) Focus group: exploration of the simulation challenges of interaction technologies (with the VEC); ii) Concept development of the front-seat passenger infotainment system and iii) Design detailing and simulation development. Each phase was briefly introduced in Chapter 3, this chapter will provide a more comprehensive presentation about the methodologies/processes followed at each phase.

4.2 Focus Group: Exploration of the Simulation Challenges of Interaction Technologies (with the VEC)

As part of the literature review, Section 2.4 "Contemporary Automotive Infotainment Solutions to Empower Front-Seat Passengers" presented the technology review of the concept cars accompanied with the discussion of the technology trends envisioned for the automotive user interfaces of future cars. The interaction technologies introduced in Section 2.4 constituted a significant reference for the design of the front-seat passenger infotainment system.

In PhD research, one of the decisions to be taken for the design and simulation development was the selection of the technologies that would enable new interactions and functionalities (infotainment features) for the front-seat passengers. The PhD research aimed to gather data about user experience of the front-seat passenger infotainment system through experience prototyping with simulation. Therefore, while shortlisting the promising interaction technologies for the design concept, the simulation challenges of these technologies needed to be identified. Since the VEC was the research partner that involved in the simulation development, the interaction technologies had to be shortlisted based on the VEC's simulation facilities and expertise. Hence, a focus group study was conducted with the VEC staff members who were asked their expert opinion on simulation challenges and opportunities for the selection of interaction technologies. Following sections will present the aims, details (participants, venue, duration), protocol and the results of the focus group study.

4.2.1 Aim

The aims of the focus group study were:

- To understand what aspects of interaction are challenging to communicate, track and modify with simulation for each interaction technology,
- To shortlist the interaction technologies for front-seat passenger infotainment system design which will be prototyped with simulation at the VEC.

4.2.2 Details of the Focus Group Study

Participant sampling and recruitment: This focus group study was conducted with four staff members from the VEC. The participants were reached and informed about the study via e-mail. Each participant was expected to satisfy at least one of the following criteria for participation in the study:

- expertise in simulation development (visualization and programming)
- knowledge about simulation equipment / technologies
- involvement in decision making in any investment of simulation technologies at the VEC

Venue: The sessions were carried out in a meeting room at the VEC, Daresbury Science Park with a TV to display the power-point presentation of the technology review and the details of the study, and a large table to distribute the study materials.

Duration: The whole session took approximately 2,5 hours in total. The session was led by the author and audio-recorded with iPhone SE to keep track of all comments made during the discussion.

4.2.3 Focus Group Study Protocol and Supporting Materials

The study protocol with a brief description/duration of each step can be found in Table 4.1. This section will then go through each step to give further details about the data collection methods and supporting research materials.

Table 4.1 Study protocol

Review of the participant information sheets and consent forms (app. 5 min)
1. Presentation (app. 20 min): Introduction of the aim and agenda of the focus group study and the interaction technologies that will be discussed
2. Completion of the discussion documents (app. 120 min): Each document is for a specific interaction technology and it includes sketches that exemplify possible applications of that technology to front-seat passenger area. Each technology/user interface is discussed through: • Capabilities of VR simulation • Challenges of/for VR simulation • Required degree of reality, equipment / spatial settings for interaction prototyping • The mini-questionnaire: Capabilities of the VEC
3. Wrap-up (app. 10 min): Shortlisting the interaction technologies

4.2.3.1 Presentation

The session started with the review of the information sheets and consent forms by the focus group participants (See Appendices 3 and 4). After they gave consent to the items listed in the consent form; the session continued with a Power Point presentation (See the slides in Appendix 5). This presentation first summarized the aim and agenda of the study which had already been explained in the participant information sheets in detail. Then the presentation continued with the main findings of the technology review of the concept cars with a specific focus on the interaction technologies envisioned for the future automotive user interfaces (See Appendix 5). However, the scope of the presentation was not limited with the list of the technologies collected via the technology review of the concept cars. Before taking them directly into consideration for the design and simulation development, eliminations and additions were applied to this list of technologies (See Figure 4.1) for the discussion.

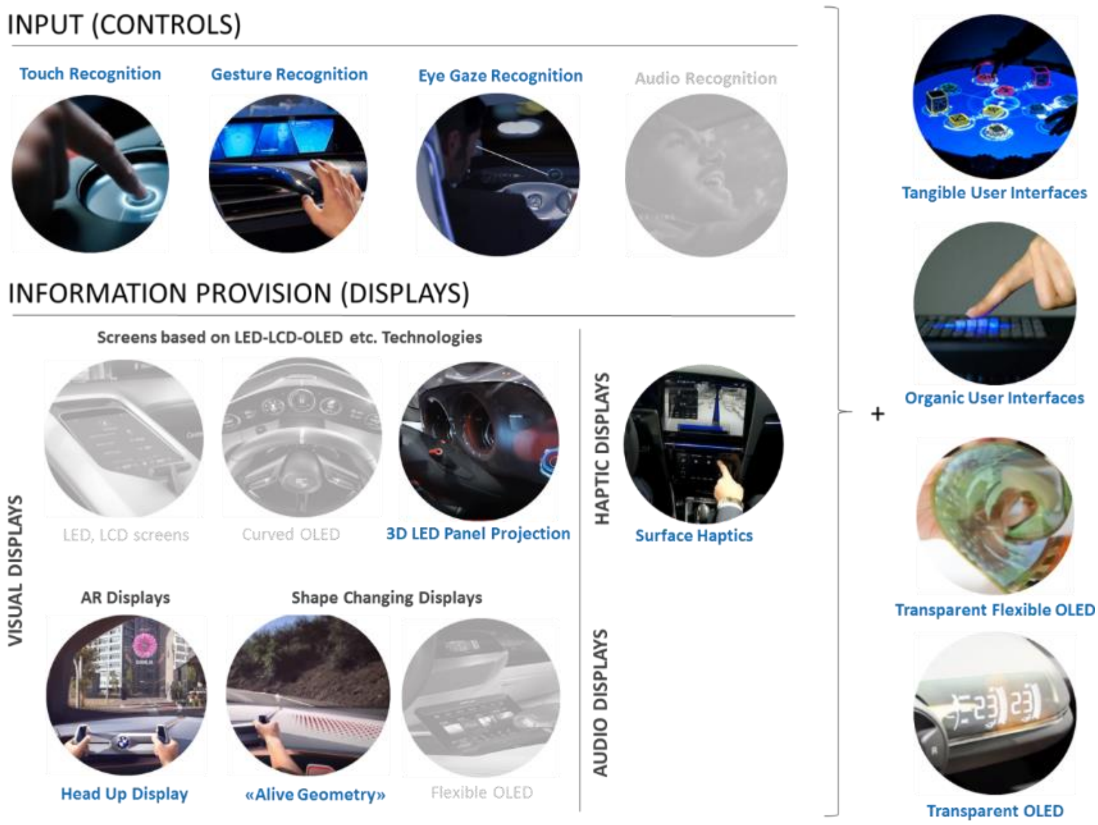


Figure 4.1 Technologies selected (and presented to the participants) for the focus group discussion

The additions to the list involved interaction technologies / interfaces which were developed or applied for other product sectors (e.g. consumer electronics) and proposed opportunities for the front seat passenger infotainment system. For example, *organic user interfaces* were partially represented in concept cars under *shape changing displays-alive geometry* as a means of visual feedback. However, changes in shape could constitute haptic feedback (display) and input. That is why *organic user interfaces* (Folman & Vertegaal, 2008) as an umbrella concept was included in the presentation and discussion. *Tangible user interfaces,* which are based on use of physical items as controls and displays of digital systems, were also taken into consideration since they brought about their own potentials and challenges for design and simulation. Other additions included *Flexible (Transparent) OLED* and *Transparent OLED* technologies because they extended the capabilities of the displays covered in the technology review with transparency and flexibility. Flexibility also pointed out potentials as a means of shape changing input, therefore, *Flexible (Transparent) OLED* was included in the presentation and discussion as an organic user interface. It is also important to note that Transparent OLED had already been considered as part of automotive user interfaces in previous auto-shows (KIA GT concept car - Frankfurt Motor

Show 2011). Nevertheless, it was not within the scope of the concept cars review in Section 2.4.

Some of the technologies collected via the technology review of the concept cars were eliminated (see greyed out in Figure 4.1) from the presentation and discussions, since their relative contributions to the front-seat passenger infotainment design or their simulation challenges were not varied or unique enough. ‘Audio recognition’ was eliminated from the list for a different reason, it was not included in the discussion because of the obvious risk of driver’s distraction.

As can be seen in Figure 4.1, the items for discussion included either specific technologies, such as *transparent OLED,* or types of user interface or an interactive feature like in the example of *gesture recognition*. Nevertheless, both interaction technologies and user interfaces will be referred as ‘interaction technology’ or ‘technology’ in the following sections for readers to identify the discussion items clearly. The slides of the Power Point presentation shown to the participants, including the definitions of each interaction technology can be seen in Appendix 5.

4.2.3.2 Discussion

This section introduces the data collection methods and the research materials that facilitated the focus group discussion. Figure 4.2 demonstrates examples of the template documents prepared for each technology to be reviewed one by one during the session. The templates which were printed on A2 size paper, were filled in by the participants and the author collectively during the discussion. Each template included initial idea sketches of the possible applications of that specific technology to front-seat passenger area (see Figure 4.3). The templates included notes on the main advantage or distinctive feature of each technology on the left of each sketch. The sketches helped the participants to imagine what aspects of interactions needed to be communicated through simulation and facilitated the discussion of the simulation challenges or opportunities.

As can be seen in Figure 4.2 each template included a chart with questions (1) and a mini questionnaire (2) to fill in:

1. Questions

- Capabilities of VR simulation: What aspects of interaction *can* be communicated/tracked/modified with VR?

- Challenges of/for VR simulation: What aspects of interaction *cannot* be communicated/tracked/modified with VR?
- What is the required degree of reality for interaction prototyping?

  What is the required equipment/spatial settings for interaction prototyping?

2. Mini questionnaire to rate each technology in terms of:

- Availability of necessary equipment settings
- Cost-need of investment
- Required time for development
- Added value to VEC (Motivation of VEC to invest in)
- Range of application in industry

Figure 4.2 The templates to be filled for each technology

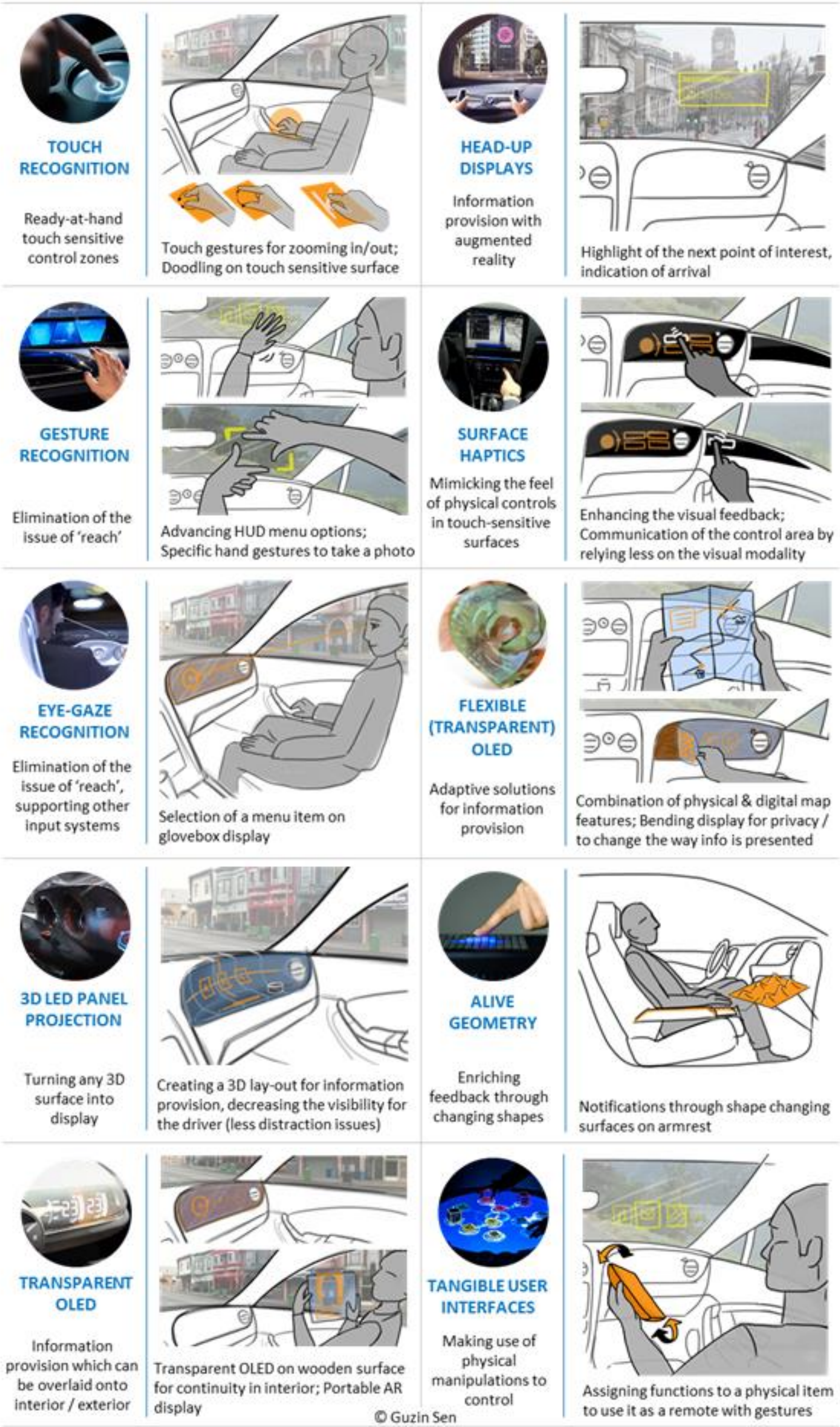


Figure 4.3 Initial idea sketches included in the templates.

In response to the first two questions (What aspects of interaction *can/cannot* be communicated/tracked/modified with VR?), the participants were expected to discuss the challenges of interaction prototyping with VR simulation regarding the aspects of interaction. To enable this discussion, the participants were provided with a reference document A (Figure 4.4), which listed the spatio-temporal aspects (e.g. speed, direction) and sensory-specific aspects (e.g. tactile: friction) of interaction. While creating the document, the synthesis diagram for the aspects of (aesthetics of) interaction was referred (Figure 2.5). As mentioned earlier in the literature review, the sensory-specific aspects are borrowed from Sener & Pedgley (2015), whereas spatio-temporal aspects are based on the motor-level attributes of Lenz et al. (2014). The reference document A did not include some interaction aspects, such as e.g. presentation or action-reaction. To enable the discussion in prototyping challenges with regards to these aspects, we would have needed design proposals for the flow of the front-seat passenger infotainment system interactions (e.g. control-feedback cycle), which goes beyond the initial ideas presented here. However, without the interaction flow, it was still possible to discuss the simulation challenges of the technologies through their sensory-specific and spatio-temporal aspects, because each technology targets certain sensory modalities and comes with its own spatio-temporal characteristics. We can also justify the exclusion of the action-reaction and presentation aspects from the discussion with the fact that these aspects are already based on the decisions regarding sensory-specific and spatio-temporal aspects and communicated through sensory modalities. Provision of the aspects of interaction with the document A deepened the discussion with more advanced questions like "*Can the speed of hand gestures be tracked?"* by moving beyond the rather less advanced questions like *"Can gestural interactions be prototyped with VR simulation?"*.

To discuss the required degree of reality, equipment / spatial settings for interaction prototyping of each technology, the participants were provided with another reference document. The document B demonstrated degrees of reality (e.g. virtual reality-augmented reality) and a list of equipment and spatial settings (e.g. finger tracking systems) to help the participants go through simulation variables that would fit to a specific interaction technology (See Figure 4.5).

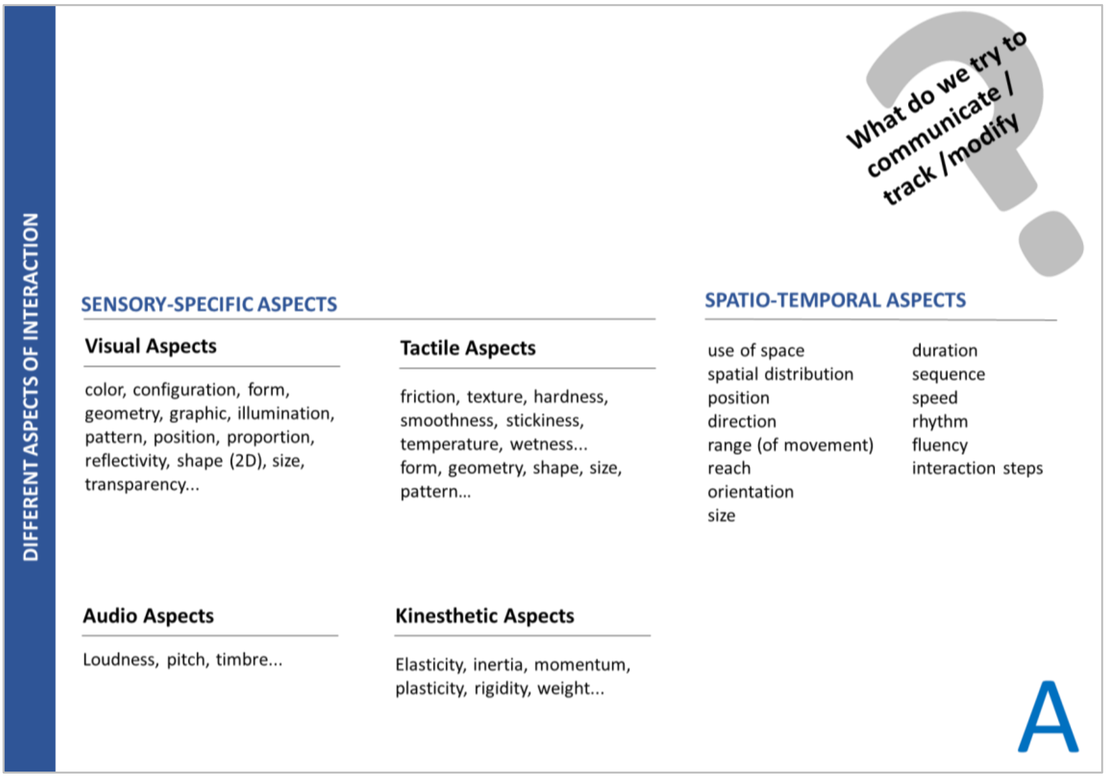


Figure 4.4 Reference document A

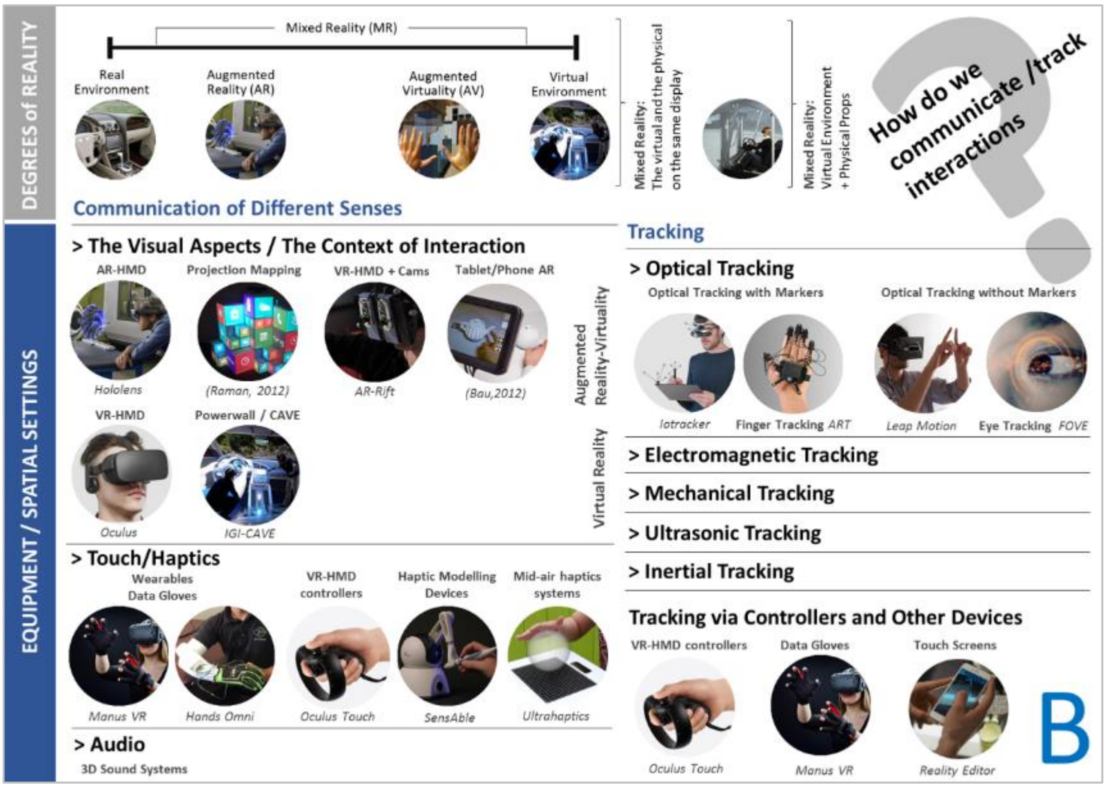


Figure 4.5 Reference document B

4.2.4 Analysis and Results of the Focus Group Study

4.2.4.1 Identification of the simulation challenges

This section presents the results of the discussion in the Tables from 4.2 to 4.11. Each table lists the diverse interaction aspects of an interaction technology that were found easy or hard to communicate/track/modify with VR Simulation. The tables also include the required degree of reality and equipment / spatial settings to achieve interaction prototyping of a user interface design embodying that specific technology. Tables finally present the results of the mini-questionnaire. It is important to mention that, for specific technologies, the participants could not provide an answer regarding the time and cost of the simulation development, since it would require further research and planning. Therefore, in the mini-questionnaire, the options provided for such questions are marked with '?'.

Table 4.2 Touch recognition related discussions and mini questionnaire

 TOUCH RECOGNITION	**1. Capabilities of VR simulation:** Interaction aspects that can be communicated /tracked/modified with VR Simulation
	Most of the visual aspects, temperature (tactile) (if needed)
	2. Challenges of/for VR simulation: Interaction aspects that are challenging to communicate/track/modify with VR Simulation
	- Position of the touch sensitive area when it is on the side (visual and spatial); *- Friction, texture, hardness, smoothness, form, size, geometry, pattern, confirmation of touch for each fingertip (tactile aspects);*
	3. Required degree of reality, equipment / spatial settings
	- Real touch sensitive surfaces/screens; or: *- Virtual reality with haptics systems (for communication of the tactile aspects) and/or finger tracking (to track complex free-form touch gestures)*

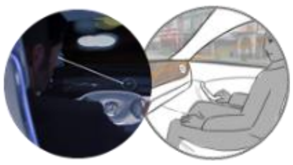
Mini questionnaire						
Availability of necessary equipment/settings	1. available in VEC	[ ]	2. can be acquired in .... time	[✓]	3. cannot be acquired	[ ]
Cost/need of investment	1. no need for investment	[ ]	2. affordable	[?]	3. not-affordable	[?]
Existence of relevant experience of the VEC Staff	1. available	[✓]	2. further exploration / training is needed	[ ]	3. unavailable	[ ]
Required time for development	1. 1-2 months	[?]	2. 2-3 months	[?]	3. more than 3 months	[?]
Added value to the VEC (Motivation to invest in)	1. no / little contribution	[ ]	2. medium-level contribution	[✓]	3. high-level contribution	[ ]
Range of application within industry	1. limited	[ ]	2. medium	[✓]	3. wide	[ ]

Table 4.3 Gesture recognition related discussions and mini questionnaire

 **GESTURE RECOGNITION**	**1. Capabilities of VR simulation:** Interaction aspects that can be communicated/tracked/modified with VR Simulation
	Most of the visual (visual feedback) and spatio-temporal aspects
	2. Challenges of/for VR simulation: Interaction aspects that are challenging to communicate/ track/modify with VR Simulation
	Identification of the gesture in high speed (spatio-temporal aspects)
	3. Required degree of reality, equipment / spatial settings
	Virtual reality (all kinds of displays) with optical hand tracking systems

Mini questionnaire						
Availability of necessary equipment/settings	1. available in VEC	[√]	2. can be acquired in .... time	[ ]	3. cannot be acquired	[ ]
Cost/need of investment	1. no need for investment	[√]	2. affordable	[ ]	3. not-affordable	[ ]
Existence of relevant experience of the VEC Staff	1. available	[√]	2. further exploration / training is needed	[ ]	3. unavailable	[ ]
Required time for development	1. 1-2 months	[?]	2. 2-3 months	[?]	3. more than 3 months	[?]
Added value to the VEC (Motivation to invest in)	1. no / little contribution	[ ]	2. medium-level contribution	[ ]	3. high-level contribution	[√]
Range of application within industry	1. limited	[ ]	2. medium	[ ]	3. wide	[√]

Table 4.4 Eye-gaze recognition related discussions and mini questionnaire

 **EYE-GAZE RECOGNITION**	**1. Capabilities of VR simulation:** Interaction aspects that can be communicated /tracked/modified with VR Simulation
	All visual and spatio-temporal aspects (with eye-tracking systems)
	2. Challenges of/for VR simulation: Interaction aspects that are challenging to communicate/track/modify with VR Simulation
	Selection/differentiation of the user interface items based on their spatial distribution and size (visual-spatial) (with eye-tracking systems)
	3. Required degree of reality, equipment / spatial settings for interaction prototyping
	Virtual reality with eye-tracking systems

Mini questionnaire						
Availability of necessary equipment/settings	1. available in VEC	[ ]	2. can be acquired in .... time	[?]	3. cannot be acquired	[?]
Cost/need of investment	1. no need for investment	[ ]	2. affordable	[ ]	3. not-affordable	[√]
Existence of relevant experience of the VEC Staff	1. available	[√]	2. further exploration / training is needed	[ ]	3. unavailable	[ ]
Required time for development	1. 1-2 months	[√]	2. 2-3 months	[ ]	3. more than 3 months	[ ]
Added value to the VEC (Motivation to invest in)	1. no / little contribution	[ ]	2. medium-level contribution	[ ]	3. high-level contribution	[√]
Range of application within industry	1. limited	[ ]	2. medium	[ ]	3. wide	[√]

Table 4.5 3D LED panel projection related discussions and mini questionnaire

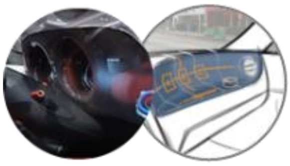
<table>
<tr><td rowspan="6">
3D LED PANEL PROJECTION</td><td colspan="6">**1. Capabilities of VR simulation:** Interaction aspects that can be communicated /tracked/modified with VR Simulation</td></tr>
<tr><td colspan="6">*Most of the visual and spatio-temporal aspects*</td></tr>
<tr><td colspan="6">**2. Challenges of/for VR simulation:** Interaction aspects that are challenging to communicate/track/modify with VR Simulation</td></tr>
<tr><td colspan="6">*- Mapping UI images to 3D non-flat surfaces (visual-spatio-temporal)*
- If the display is touch sensitive: Friction, texture, hardness, smoothness, form, size, geometry, pattern (tactile aspects)</td></tr>
<tr><td colspan="6">**3. Required degree of reality, equipment / spatial settings** for interaction prototyping</td></tr>
<tr><td colspan="6">*- Virtual reality systems*
- If the display is touch sensitive: Mixed reality (e.g. transparent mock-ups not to occlude optical hand tracking) to communicate the tactile aspects e.g. form</td></tr>
<tr><td colspan="7">**Mini questionnaire**</td></tr>
<tr><td>**Availability of necessary equipment/settings**</td><td>1. available in VEC</td><td>[ ]</td><td>2. can be acquired in .... time</td><td>[√]</td><td>3. cannot be acquired</td><td>[ ]</td></tr>
<tr><td>**Cost/need of investment**</td><td>1. no need for investment</td><td>[?]</td><td>2. affordable</td><td>[?]</td><td>3. not-affordable</td><td>[?]</td></tr>
<tr><td>**Existence of relevant experience of the VEC Staff**</td><td>1. available</td><td>[?]</td><td>2. further exploration / training is needed</td><td>[?]</td><td>3. unavailable</td><td>[?]</td></tr>
<tr><td>**Required time for development**</td><td>1. 1-2 months</td><td>[?]</td><td>2. 2-3 months</td><td>[?]</td><td>3. more than 3 months</td><td>[?]</td></tr>
<tr><td>**Added value to the VEC (Motivation to invest in)**</td><td>1. no / little contribution</td><td>[√]</td><td>2. medium-level contribution</td><td>[ ]</td><td>3. high-level contribution</td><td>[ ]</td></tr>
<tr><td>**Range of application within industry**</td><td>1. limited</td><td>[√]</td><td>2. medium</td><td>[ ]</td><td>3. wide</td><td>[ ]</td></tr>
</table>

Table 4.6 Transparent OLED related discussions and mini questionnaire

<table>
<tr><td rowspan="6">
TRANSPARENT OLED</td><td colspan="6">**1. Capabilities of VR simulation:** Interaction aspects that can be communicated /tracked/modified with VR Simulation</td></tr>
<tr><td colspan="6">*Most of the visual and spatio-temporal aspects*</td></tr>
<tr><td colspan="6">**2. Challenges of/for VR simulation:** Interaction aspects that are challenging to communicate/track/modify with VR Simulation</td></tr>
<tr><td colspan="6">*If there is a portable T-OLED display: friction, texture, hardness, smoothness, stickiness, form, size, geometry, pattern (tactile); weight (kinesthetic), mapping user interface images onto moving display and onto elements of dynamic outside environment*</td></tr>
<tr><td colspan="6">**3. Required degree of reality, equipment / spatial settings** for interaction prototyping</td></tr>
<tr><td colspan="6">*- If there is a fixed T-OLED display: VR systems (all types of display)*
- If there is a portable T-OLED display: Mixed reality (a physical mock-up with markers and AR-HMD for digital user interface to be superimposed on the physical mock-up); OR, a tablet with AR applications</td></tr>
<tr><td colspan="7">**Mini questionnaire**</td></tr>
<tr><td>**Availability of necessary equipment/settings**</td><td>1. available in VEC</td><td>[?]</td><td>2. can be acquired in .... time</td><td>[?]</td><td>3. cannot be acquired</td><td>[?]</td></tr>
<tr><td>**Cost/need of investment**</td><td>1. no need for investment</td><td>[?]</td><td>2. affordable</td><td>[?]</td><td>3. not-affordable</td><td>[?]</td></tr>
<tr><td>**Existence of relevant experience of the VEC Staff**</td><td>1. available</td><td>[√]</td><td>2. further exploration / training is needed</td><td>[ ]</td><td>3. unavailable</td><td>[ ]</td></tr>
<tr><td>**Required time for development**</td><td>1. 1-2 months</td><td>[ ]</td><td>2. 2-3 months</td><td>[ ]</td><td>3. more than 3 months</td><td>[√]</td></tr>
<tr><td>**Added value to the VEC (Motivation to invest in)**</td><td>1. no / little contribution</td><td>[ ]</td><td>2. medium-level contribution</td><td>[ ]</td><td>3. high-level contribution</td><td>[√]</td></tr>
<tr><td>**Range of application within industry**</td><td>1. limited</td><td>[ ]</td><td>2. medium</td><td>[ ]</td><td>3. wide</td><td>[√]</td></tr>
</table>

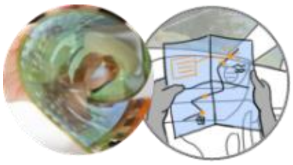
Table 4.7 Head-up displays related discussions and mini questionnaire

<table>
<tr><td rowspan="6">
HEAD-UP DISPLAYS</td><td colspan="6">**1. Capabilities of VR simulation:** Interaction aspects that can be communicated /tracked/modified with VR Simulation</td></tr>
<tr><td colspan="6">*Most of the visual and spatio-temporal aspects*</td></tr>
<tr><td colspan="6">**2. Challenges of/for VR simulation:** Interaction aspects that are challenging to communicate/track/modify with VR Simulation</td></tr>
<tr><td colspan="6">*Superimposing the digital user interface images onto the elements of dynamic outside environment: Adjusting the position, direction, orientation, duration, speed etc. (visual, spatio-temporal aspects)*</td></tr>
<tr><td colspan="6">**3. Required degree of reality, equipment / spatial settings** for interaction prototyping</td></tr>
<tr><td colspan="6">*Virtual reality systems (all types of display)*</td></tr>
<tr><td colspan="7">**Mini questionnaire**</td></tr>
<tr><td>**Availability of necessary equipment/settings**</td><td>1. available in VEC</td><td>[✓]</td><td>2. can be acquired in .... time</td><td>[ ]</td><td>3. cannot be acquired</td><td>[ ]</td></tr>
<tr><td>**Cost/need of investment**</td><td>1. no need for investment</td><td>[✓]</td><td>2. affordable</td><td>[ ]</td><td>3. not-affordable</td><td>[ ]</td></tr>
<tr><td>**Existence of relevant experience of the VEC Staff**</td><td>1. available</td><td>[ ]</td><td>2. further exploration / training is needed</td><td>[✓]</td><td>3. unavailable</td><td>[ ]</td></tr>
<tr><td>**Required time for development**</td><td>1. 1-2 months</td><td>[?]</td><td>2. 2-3 months</td><td>[?]</td><td>3. more than 3 months</td><td>[?]</td></tr>
<tr><td>**Added value to the VEC (Motivation to invest in)**</td><td>1. no / little contribution</td><td>[ ]</td><td>2. medium-level contribution</td><td>[✓]</td><td>3. high-level contribution</td><td>[ ]</td></tr>
<tr><td>**Range of application within industry**</td><td>1. limited</td><td>[ ]</td><td>2. medium</td><td>[✓]</td><td>3. wide</td><td>[ ]</td></tr>
</table>

Table 4.8 Surface haptics related discussions and mini questionnaire

<table>
<tr><td rowspan="6">
SURFACE HAPTICS</td><td colspan="6">**1. Capabilities of VR simulation:** Interaction aspects that can be communicated /tracked/modified with VR Simulation</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">**2. Challenges of/for VR simulation:** Interaction aspects that are challenging to communicate/track/ modify with VR Simulation</td></tr>
<tr><td colspan="6">*- Friction, texture, hardness, smoothness, form, size, geometry, pattern, confirmation of touch for each fingertip (tactile aspects)*</td></tr>
<tr><td colspan="6">**3. Required degree of reality, equipment / spatial settings** for interaction prototyping</td></tr>
<tr><td colspan="6">*- Virtual reality with surface haptics systems*</td></tr>
<tr><td colspan="7">**Mini questionnaire**</td></tr>
<tr><td>**Availability of necessary equipment/settings**</td><td>1. available in VEC</td><td>[?]</td><td>2. can be acquired in .... time</td><td>[?]</td><td>3. cannot be acquired</td><td>[?]</td></tr>
<tr><td>**Cost/need of investment**</td><td>1. no need for investment</td><td>[?]</td><td>2. affordable</td><td>[?]</td><td>3. not-affordable</td><td>[?]</td></tr>
<tr><td>**Existence of relevant experience of the VEC Staff**</td><td>1. available</td><td>[✓]</td><td>2. further exploration / training is needed</td><td>[ ]</td><td>3. unavailable</td><td>[ ]</td></tr>
<tr><td>**Required time for development**</td><td>1. 1-2 months</td><td>[ ]</td><td>2. 2-3 months</td><td>[✓]</td><td>3. more than 3 months</td><td>[ ]</td></tr>
<tr><td>**Added value to the VEC (Motivation to invest in)**</td><td>1. no / little contribution</td><td>[ ]</td><td>2. medium-level contribution</td><td>[ ]</td><td>3. high-level contribution</td><td>[✓]</td></tr>
<tr><td>**Range of application within industry**</td><td>1. limited</td><td>[ ]</td><td>2. medium</td><td>[ ]</td><td>3. wide</td><td>[✓]</td></tr>
</table>

Table 4.9 Flexible OLED related discussions and mini questionnaire

	**1. Capabilities of VR simulation:** Interaction aspects that can be communicated /tracked/modified with VR Simulation
FLEXIBLE (TRANSPARENT) OLED	*Most of the visual and spatio-temporal aspects*
	2. Challenges of/for VR simulation: Interaction aspects that are challenging to communicate/track/modify with VR Simulation
	Mapping digital user interface images onto changing 3D surface (visual, spatio-temporal); friction, texture, hardness, smoothness, form, size, geometry, pattern (tactile); elasticity, plasticity, rigidity, weight (kinesthetic)
	3. Required degree of reality, equipment / spatial settings for interaction prototyping
	Mixed reality (a physical mock-up with markers and AR-HMD for digital user interface to be superimposed on the physical mock-up)

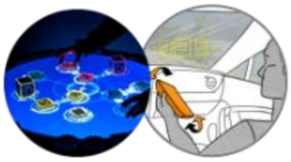
Mini questionnaire						
Availability of necessary equipment/settings	1. available in VEC	[ ]	2. can be acquired in .... time	[ ]	3. cannot be acquired	[√]
Cost/need of investment	1. no need for investment	[ ]	2. affordable	[ ]	3. not-affordable	[√]
Existence of relevant experience of the VEC Staff	1. available	[ ]	2. further exploration / training is needed	[√]	3. unavailable	[ ]
Required time for development	1. 1-2 months	[ ]	2. 2-3 months	[ ]	3. more than 3 months	[√]
Added value to the VEC (Motivation to invest in)	1. no / little contribution	[√]	2. medium-level contribution	[ ]	3. high-level contribution	[ ]
Range of application within industry	1. limited	[√]	2. medium	[ ]	3. wide	[ ]

Table 4.10 Alive geometry related discussions and mini questionnaire

	**1. Capabilities of VR simulation:** Interaction aspects that can be communicated /tracked/modified with VR Simulation
ALIVE GEOMETRY	*All visual and spatio-temporal aspects*
	2. Challenges of/for VR simulation: Interaction aspects that are challenging to communicate/track/modify with VR Simulation
	If used as haptic feedback: Friction, texture, hardness, smoothness, form, size, geometry, pattern (tactile)
	3. Required degree of reality, equipment / spatial settings for interaction prototyping
	- If used only as visual feedback: Virtual reality *- If used as haptic feedback: Virtual reality with haptics systems or mixed reality (interactive physical mock-up of the alive geometry)*

Mini questionnaire						
Availability of necessary equipment/settings	1. available in VEC	[ ]	2. can be acquired in .... time	[ ]	3. cannot be acquired	[√]
Cost/need of investment	1. no need for investment	[ ]	2. affordable	[ ]	3. not-affordable	[√]
Existence of relevant experience of the VEC Staff	1. available	[√]	2. further exploration / training is needed	[ ]	3. unavailable	[ ]
Required time for development	1. 1-2 months	[ ]	2. 2-3 months	[ ]	3. more than 3 months	[√]
Added value to the VEC (Motivation to invest in)	1. no / little contribution	[√]	2. medium-level contribution	[ ]	3. high-level contribution	[ ]
Range of application within industry	1. limited	[ ]	2. medium	[√]	3. wide	[ ]

Table 4.11 Tangible user interfaces related discussions and mini questionnaire

<table>
<tr><td rowspan="6">
TANGIBLE
USER INTERFACES</td><td colspan="6">1. Capabilities of VR simulation: Interaction aspects that can be communicated /tracked/modified with VR Simulation</td></tr>
<tr><td colspan="6">All visual and spatio-temporal aspects</td></tr>
<tr><td colspan="6">2. Challenges of/for VR simulation: Interaction aspects that are challenging to communicate/track/modify with VR Simulation</td></tr>
<tr><td colspan="6">Friction, texture, hardness, smoothness, form, size, geometry, pattern (tactile), weight (kinesthetic)</td></tr>
<tr><td colspan="6">3. Required degree of reality, equipment / spatial settings
for interaction prototyping</td></tr>
<tr><td colspan="6">Mixed Reality (Physical mock-up with optical tracking markers)</td></tr>
<tr><td colspan="7">Mini questionnaire</td></tr>
<tr><td>Availability of necessary equipment/settings</td><td>1. available in VEC</td><td>[✓]</td><td>2. can be acquired in .... time</td><td>[ ]</td><td>3. cannot be acquired</td><td>[ ]</td></tr>
<tr><td>Cost/need of investment</td><td>1. no need for investment</td><td>[ ]</td><td>2. affordable</td><td>[✓]</td><td>3. not-affordable</td><td>[ ]</td></tr>
<tr><td>Existence of relevant experience of the VEC Staff</td><td>1. available</td><td>[✓]</td><td>2. further exploration / training is needed</td><td>[ ]</td><td>3. unavailable</td><td>[ ]</td></tr>
<tr><td>Required time for development</td><td>1. 1-2 months</td><td>[✓]</td><td>2. 2-3 months</td><td>[ ]</td><td>3. more than 3 months</td><td>[ ]</td></tr>
<tr><td>Added value to the VEC (Motivation to invest in)</td><td>1. no / little contribution</td><td>[ ]</td><td>2. medium-level contribution</td><td>[✓]</td><td>3. high-level contribution</td><td>[ ]</td></tr>
<tr><td>Range of application within industry</td><td>1. limited</td><td>[ ]</td><td>2. medium</td><td>[✓]</td><td>3. wide</td><td>[ ]</td></tr>
</table>

4.2.4.2 Wrap-up: Shortlisting the technologies

To wrap-up the discussion session, the participants of the focus group were asked to put the interaction technologies in rank order by taking into consideration: i) the simulation effort needed, ii) availability of simulation technologies and expertise at VEC to prototype these technologies, and iii) the range of application in industry.

In order to facilitate the wrap-up session, the participants were provided with paper cards that included the representative visual and the name of each technology. As a reminder, the cards also included the initial idea sketch that showed an example application of that technology to the front-seat passenger infotainment system as a control and/or display alternative (see Figure 4.6).

As mentioned earlier, each technology was handled individually in the discussion session. Asking participants to put the technologies in rank order based on the above-mentioned criteria enabled a comparative evaluation of the simulation challenges of the technologies and facilitated the shortlisting process. The shortlisting criteria were proposed as the combination of the several mini-questionnaire items. For example, 'simulation effort needed' was highly related with the existence of the relevant experience of the VEC staff and the required time for development. Similarly, access to the required simulation technologies and existence of relevant expertise were combined as 'availability of simulation technologies and expertise at the VEC'. It was also observed that the motivation of the VEC to invest in the simulation of a design with a specific technology was generally based on its range of application in industry. Therefore, the third criterion to refer while putting the technologies in rank order was their 'range of application in industry'. Please refer to Figures 4.7, 4.8, 4.9 to see the results of the discussion wrap-up.

Figure 4.6 Putting 'technology cards' in order based on the criteria written on post-its

Figure 4.7 Technologies ordered based on the simulation effort needed

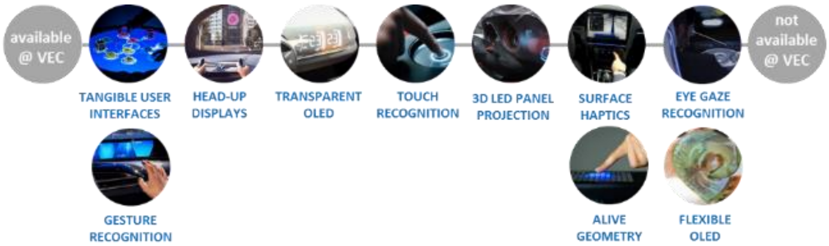


Figure 4.8 Technologies ordered based on availability of simulation technologies and expertise at the VEC

Figure 4.9 Technologies ordered based on their range of application in industry

4.2.5 Conclusions of the Focus Group Study

The results showed that the challenges of the VR simulation of an interaction technology application could only be explained with the prototyping challenges of the interaction aspects that it pointed out. In fact, the interaction aspects could vary within one specific technology depending on the way the technology was embodied in the user interface design. We can exemplify this argument through diverse applications of a transparent OLED display (See Figure 4.3). It was stated by the participants that the simulation challenge was expected to increase when it was utilized as a portable display in comparison with the fixed display version. Portable display required communication of tactile and kinesthetic aspects (e.g. weight) and pointed out difficulties in delivering some spatio-temporal aspects of interaction such as mapping user interface images onto the portable display in motion. The same argument was also applicable to organic user interfaces depending on if they were used as a means of input or output, or, as a means of visual or haptic feedback. Therefore, if we handle the challenges of interaction prototyping with VR in a less technology-bounded way, the relative degree of challenge to communicate/track/modify these diverse aspects of interaction can be visualized as in Figure 4.10.

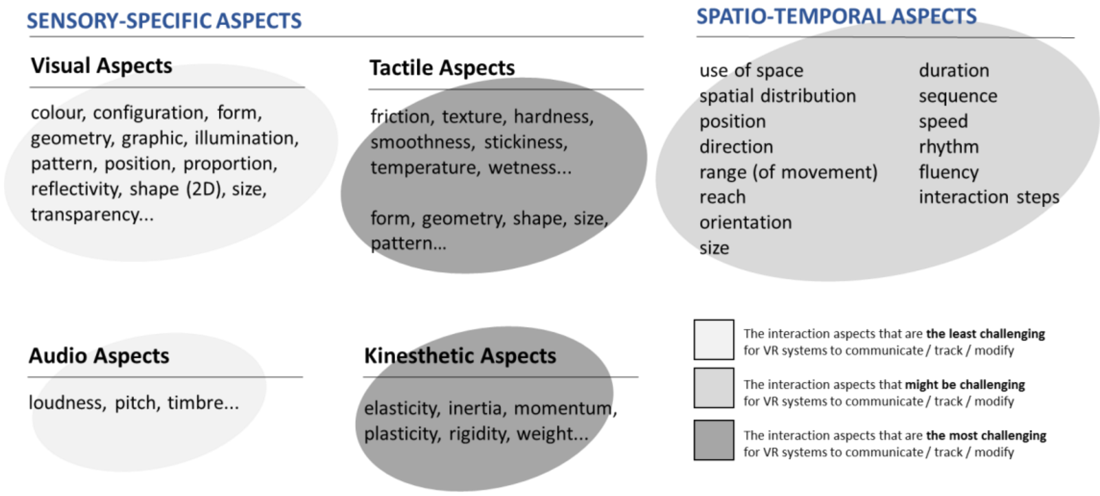


Figure 4.10 The aspects of interaction that are easy or hard to communicate/track/modify with VR systems

The solutions provided by all participants to communicate/track/modify the tactile and kinesthetic aspects of the interaction included using haptic displays and controls to augment VR systems; or, use of mixed/augmented reality with addition of interactive/non-interactive physical props to the simulation setting. *Haptic displays and controls* were mentioned for the technologies e.g. touch recognition and surface haptics. *Interactive physical prototypes* were suggested as a solution when there was a shape changing haptic feedback as in the case of alive geometry, since it was more challenging for haptic systems to communicate some tactile aspects like form and size. *Physical props (with optical tracking markers)* were mentioned as solution where a portable/malleable/graspable physical item was used as means of control and display (e.g. portable transparent OLED, flexible transparent OLED, tangible user interfaces, a touch sensitive 3D non-flat display using 3D LED panel projection).

It was also observed that, to communicate the interaction aesthetics that is brought by the embodiment of specific interaction technologies (e.g. eye-gaze recognition, surface haptics, gesture recognition) within the infotainment system, the simulation technology and the interaction technology that will be prototyped may need to be the same or very similar in working principle.

4.3 Concept Development of the Front-Seat Passenger Infotainment System

This section presents the concept development of the front-seat passenger infotainment system and the review of the design proposals with the Bentley Motors HMI Design team in Crewe, UK. The design proposals included new infotainment features (functionalities, *what*) and *how* these functionalities were going to be delivered to front-seat passenger through the user interface within the luxury Bentley Continental GT car. However, the system could be best discussed in the context of travel. Therefore, the functionalities and interactions were developed and presented within a travel scenario that would fit to the explorative nature of grand-tour car travels, which was defined by the Bentley Motors as "luxury of spontaneity" (2015).

The design of the *how* dimension of the infotainment system was based on the application of the interaction technologies presented, discussed and shortlisted for the design and simulation development in the focus group study conducted with the VEC staff. At this stage of the design, the scope of the solutions regarding the front-seat passenger infotainment system interactions were limited with the control and display alternatives rather than proposals for how each aspect of aesthetics of interaction could be. The decisions regarding all aspects of interaction (sensory-specific, spatio-temporal, action-reaction, presentation) were detailed in following stages of design and simulation development when all partners of the research (i.e. the VEC and Bentley Motors) reached a consensus on the interaction technologies that would be used in the design (which was going to be prototyped with simulation). Most of the aesthetics of interaction-related decisions were finalized while visualizing the GUI and programming the interactions for the simulation development, since it was the process when the parameters regarding most of these aspects (e.g. the duration of an animation) were defined through trials.

The design of the *what* dimension of the infotainment system, in other words, the design proposals for the new functionalities included a balanced distribution of *information*, *entertainment* and *communication* features for a connected travel scenario in Bentley GT. The themes for the functionalities were introduced earlier in the analysis of the passenger-oriented academic studies and automotive user interface concepts and they constituted a significant reference in the development of new infotainment features as well.

Following sections will first present the front-seat passenger infotainment features within the travel scenario, then introduce the control and display alternatives based on the promising interaction technologies that were found out in the focus group study. Presentation of the design proposals will also include the *why* dimension through the explanation of how each infotainment feature or control/display alternative was expected to deliver luxury values, hedonic and pragmatic qualities of user experience.

4.3.1 Front-Seat Passenger Infotainment Features within the Travel Scenario

This section presents the infotainment features proposed and illustrated by the author as part of the many steps of a car journey based on varied temporal and spatial contexts that may require specific information/entertainment/communication feature. The illustrations of the travel scenario with the new functionalities (infotainment features) can be seen in Figures 4.11 and 4.12.

1. **Activation of the system and greeting:** The journey starts with the activation of the system by the passenger. The passenger is greeted by the system with an animation that includes the Bentley Motors logo.

   The addition of this 'content' was expected to reproduce 'the symbolic value' of the Bentley Motors by reminding the passenger that he/she was about to enjoy a journey in a Bentley Continental GT.

2. **Receiving and viewing the journey plan:** This infotainment feature is about sharing of the journey plan between the driver and the front-seat passenger. The journey plan includes the list of destinations, weather forecast for each destination, estimated arrival time, the distance left to each destination, the current speed of the car, and the location of the car in relation to overall journey route.

   This feature was expected contribute to the experience of the front-seat passenger in several ways: In terms of *functional/pragmatic quality* it was expected to increase the *competence and control* of the passengers by enabling them to access all the key information about the travel. This feature was also believed to support *relatedness* among the car occupants through information exchange.

3. **Taking a photo of the view:** This feature makes use of 360 or 180-degree-cameras of the car to take a picture of its surroundings as a memory from that specific location. Therefore, the displays of the car (See options in Figure 4.15) turn into viewfinders of the camera for this feature.

This feature was added as a means of *stimulation* to make front-seat passengers more engaged in the journey through recording the journey with novel means of interaction. It was also expected to contribute to *evocation* by provoking memories of that unique journey in the longer term.

4. **Car as a tour guide: Receiving a café suggestion:** Based on the pre-defined settings and cloud data the car provides POI (point of interest) or event suggestions that car occupant might be interested in.

   This infotainment feature was added as another functionality that would support the idea of 'luxury of spontaneity'. These suggestions were expected to be a source of *stimulation* for front-seat passengers by keeping them engaged in the journey through the surroundings information and by enabling them to discover new places/events. Accessing to such customised information and making discoveries were also expected to make front-seat passengers feel more *competent* and *in control* and contribute to their *self-actualization.*

5. **Giving a coffee break (Taking a selfie at the newly discovered café):** This step was included to demonstrate the share of information (e.g. the photo) between the car and personal mobile devices through cloud.

   This feature was considered as a continuation of the *stimulation* provided by the car by bridging different spatial contexts (in this case, the newly discovered café & the car) with connected entertainment features. This was expected to enable *evocation* of the unique memories of the journey by involving the information about the spatial context that was outside of the car but reached by the car.

6. **Viewing the updated journey plan (with geo-marked photos):** This task includes viewing the updates to the journey plan (e.g. change of arrival times) after stopover. The same feature also functions as the record of travel history with addition of geo-marked photos and stopover points.

   As mentioned in 'receiving and viewing the journey plan', this feature was also proposed to increase the *competence* and *control* of the passengers by enabling them to access all the updated key information about the travel. Through the record of the travel history with addition of geo-marked photos and stopover points, the passengers were going to be able to reflect on the earlier phases of that specific journey or the past travelling experiences (*evocation*).

7. **Listening to music, viewing playlist in relation to journey plan:** This feature enables passenger to choose/view entertainment options (in this case it is music) based on the journey plan (e.g. the song that will play upon arrival to a stopover point).

   Media players are the default entertainment features provided in infotainment systems. However, this feature was added not only to make the media player more accessible to the front-seat passenger, but also to make it different from other media players by creating a bond between the means of *stimulation* and the journey itself.

8. **Reading:** This feature makes use of car displays for reading activities to lessen/eliminate the motion sickness caused by the 'heads down' reading. In this scenario the reading activity is presented as part of a communication feature, which is access to e-mails.

   The contribution of this infotainment feature to user experience of front-seat passengers may vary depending on the content of the reading material, however it was proposed to be another source of *stimulation* during the journey. This functionality was included in this travel scenario to explore if the utilization of the digital car displays (e.g. bigger pages or fonts to increase readability, more comfortable reading posture) would contribute to the *functional/pragmatic value* of the experience.

9. **Volume adjustment (while resting/sleeping):** Volume adjustment was added to the travel scenario not as a new infotainment feature but as a challenging task that requires a type of control which is easier to access.

10. **Doodling with AR brush in traffic jam:** This feature makes use of AR to doodle onto the surroundings of the car.

    This infotainment feature was provided to take advantage of the waiting time in traffic jams by enabling passengers to engage in a stimulating infotainment activity that involved the surroundings of the car. It provided a more creative and personal way to keep record of the journey and to utilize the time that might otherwise have been lost. Therefore, in addition to the *stimulation*, it was also expected to contribute the competence of the passenger through efficient utilization of time, as well as, *evocation* and/or *self-actualization* through involvement in creative documentation of a fragment of each unique journey.

11. **Notification-Approaching to the stopover point:** This feature gives front-seat passengers enough time before arrival to get ready to alight (to check how they look, prepare their belongings).

    As in previous information features (e.g. viewing journey plan), receiving the information that 'the car is approaching to the stopover place soon' was also expected to make front-seat passenger feel more *competent* and *in-control.* This feature automatically answered the "Are we there yet?" question that would have been asked to the driver or checked through the location services of other devices. Satisfaction of such anticipation (or the anticipation of the fact that the car will notify the user) was also expected to contribute the *autonomy* of the front-seat passengers.

12. **Notification-Arrival to the stopover point:** This feature enables passenger to identify the exact building/point they aim to arrive at with the use of AR.

    The expected contributions of the previous feature (notification of the car approaching the stopover point) to the user experience of the front-seat passenger also apply to this feature.

13. **De-activation of the system:** The journey ends with the de-activation of the system by the passenger and the appearance of the animation of the Bentley Motors Logo.

    It was considered as a visual way for the car saying, "until next time" and as a reminder of the *symbolic value* of the car through the Bentley Motors logo.

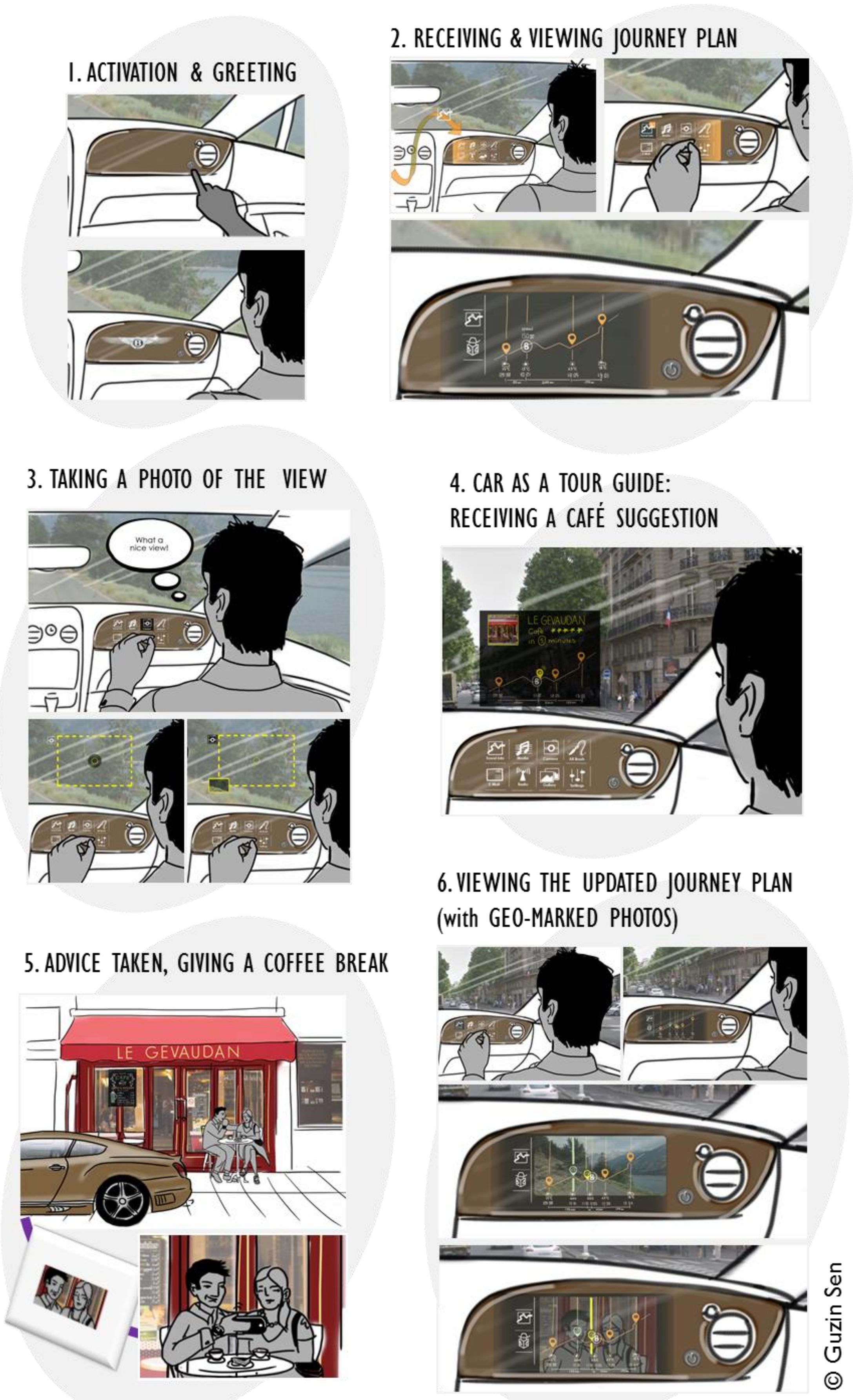


Figure 4.11 Front-seat passenger infotainment features within the travel scenario - 1

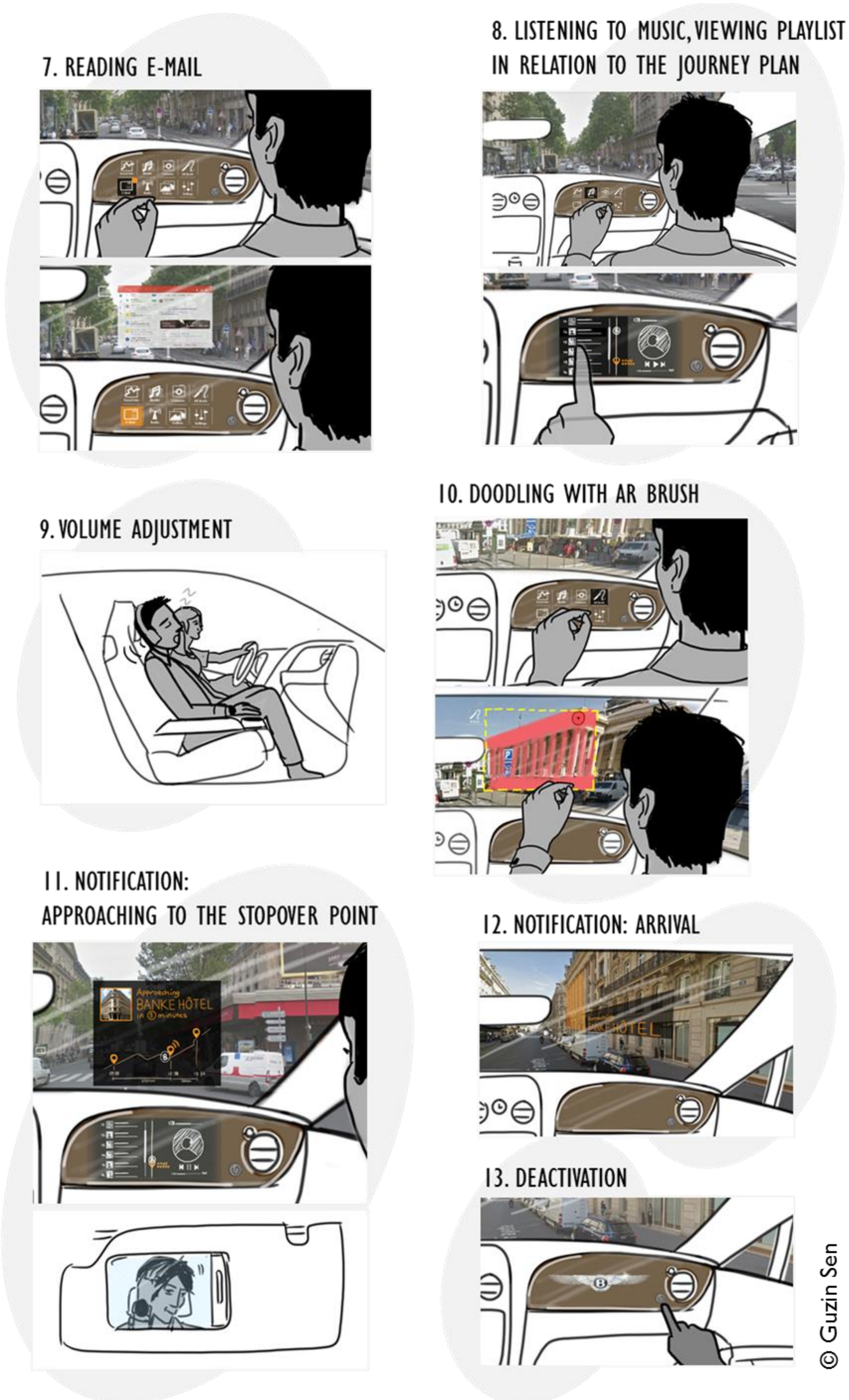


Figure 4.12 Front-seat passenger infotainment features within the travel scenario - 2

4.3.2 Control and Display Alternatives

Previous section presented the travel scenario that was comprised of new infotainment features and relevant interaction tasks that would make sense in separate phases of the journey. The scenario visuals in Figure 4.11 and 4.12 already incorporated a selection of control and display alternatives to communicate these functionalities. This section will present the control (input) and display (output, information provision) alternatives (proposed and illustrated by the author) as the varied ways to deliver the presented functionalities to the user.

4.3.2.1 Control alternatives

Control alternatives (See Figure 4.13) presented for the front-seat passenger infotainment system include the following:

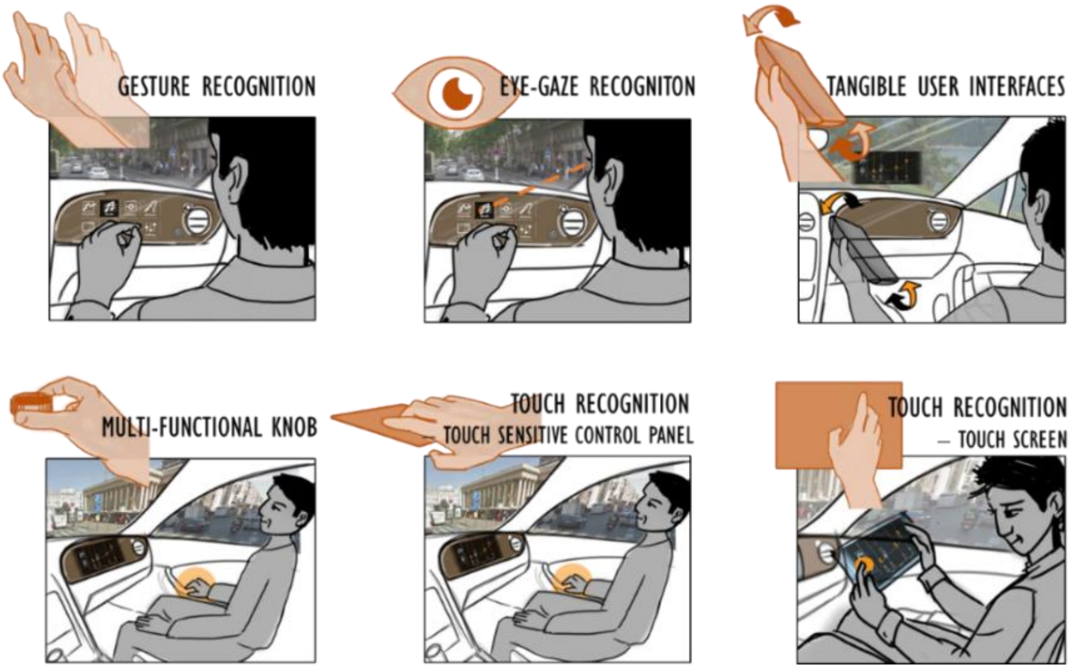


Figure 4.13 Control alternatives

1. **Gesture Recognition:** Use of hand-finger movements to control the infotainment system which requires less reliance on the physical controls and eliminates the issue of 'reach'

2. **Eye-Gaze Recognition**: It was offered to support other input systems rather than to be used on its own. Knowing where users are looking at enables us to understand what information users would like to interact. This way other input systems can be just used for confirmation/activation of the related function.

3. **Tangible User Interfaces**: A portable physical controller is manipulated by tilting-shaking etc. (device-based gestures) to control the system. However, it raises concerns regarding the time and physical effort to handle and manipulate the physical controller to provide input to the system each time.

4. **Multi-Functional Knob:** It is a control type which is currently used in cars to integrate as many functions/manipulations as possible. The users can rotate or toggle the knob as well as they can use the touch sensitive top surface to control the infotainment system.

5. **Touch Recognition - Touch Sensitive Surface:** Controlling the infotainment system through a ready-at-hand touch sensitive area (e.g. armrest area)

6. **Touch Recognition - Touch Screen:** This control alternative is provided for the display alternatives (fixed/portable transparent OLED, see the options 2 and 3 in Figure 4.13) which can also be used as a means of control.

4.3.2.2 Display (information provision) alternatives

As can be seen in Figure 4.14, the display alternatives for the front-seat passenger infotainment system included one display technology combination of two display technologies:

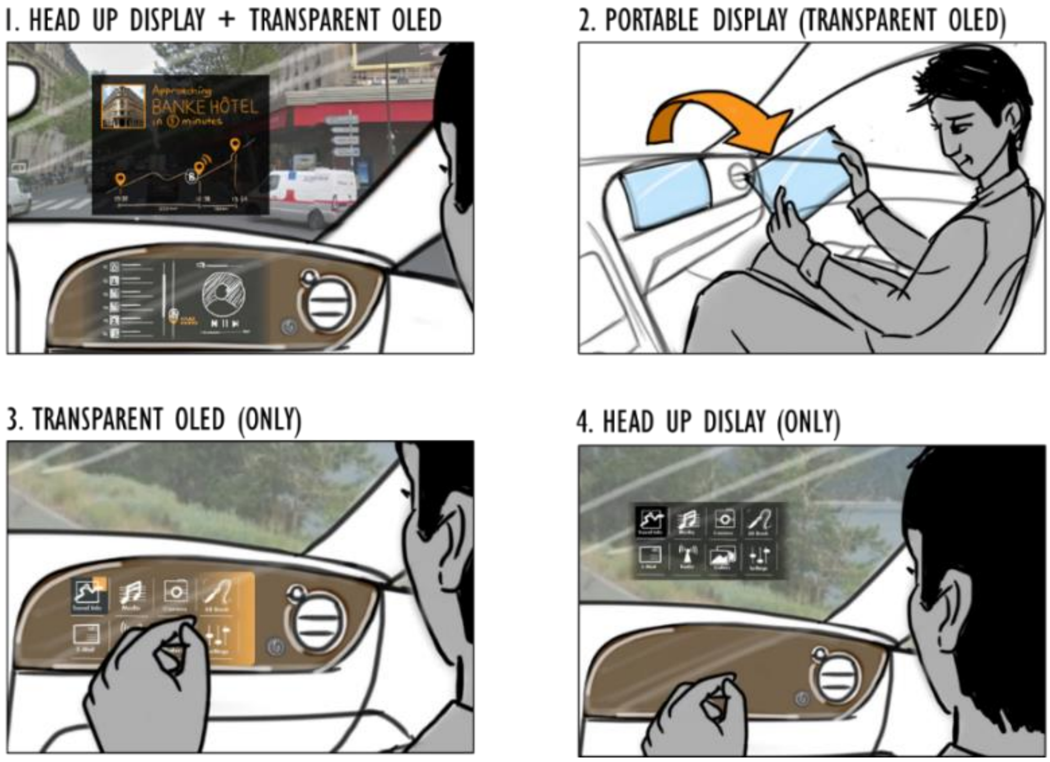


Figure 4.14 Display alternatives

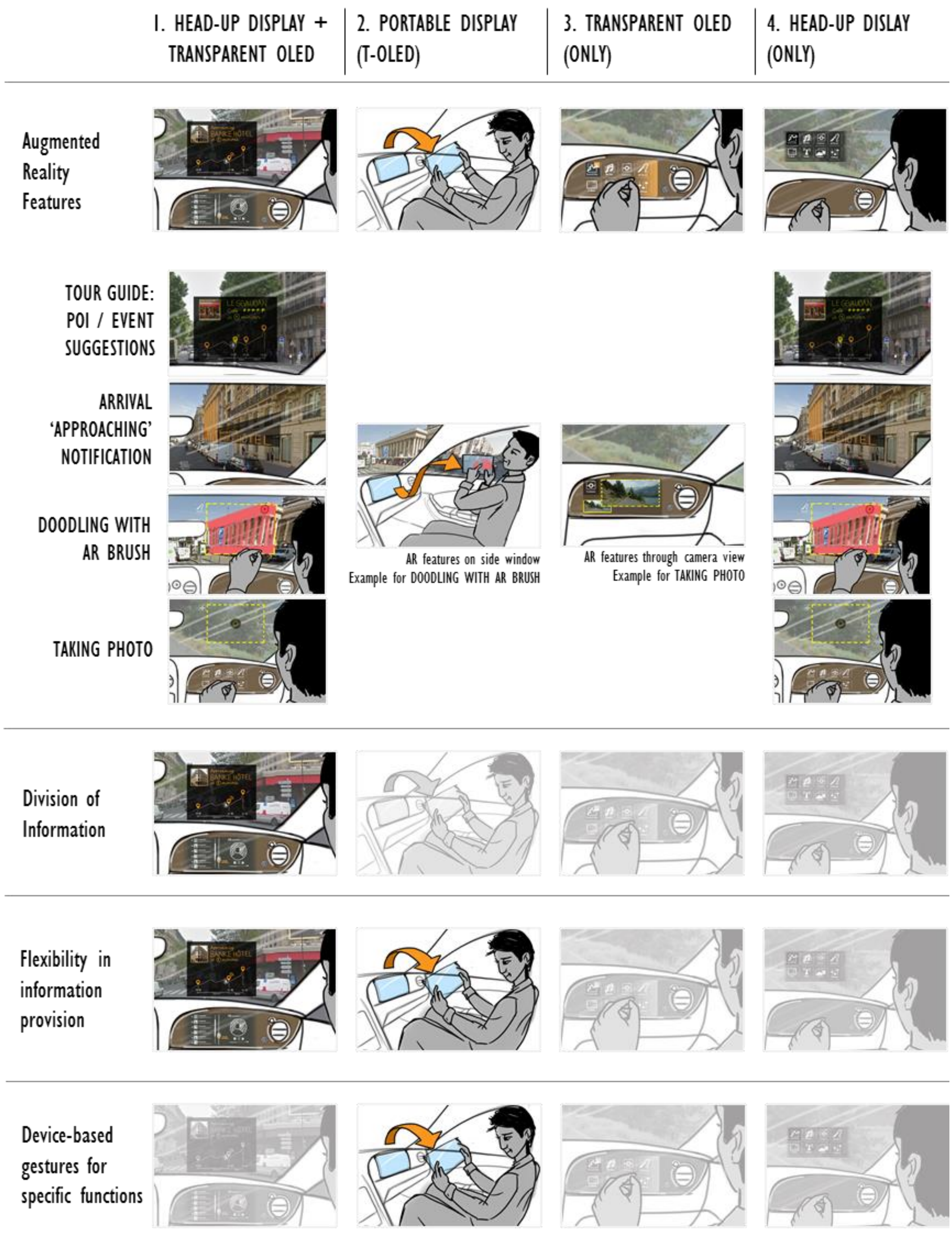


Figure 4.15 Comparison of display alternatives for the front-seat infotainment system

Each display alternative was proposed to enable the front-seat passengers to perform all the infotainment tasks mentioned in travel scenario, but some alternatives had their own advantages over the others regarding the execution of specific infotainment features. Figure 4.15 presents the comparison of the display alternatives. First it shows which displays are more advantageous regarding the execution of AR-enabled infotainment features (e.g. taking photo, arrival notification). For example, head up display offers a more 'direct' augmentation of the outside environment, whereas the same AR feature is also possible with the fixed transparent OLED display if the camera view of the outside environment is shown on the screen. The second advantage point is division of information, which can be achieved by the combination of two displays without sacrificing from the size of the user interface. Thirdly, the alternatives are compared in terms of the flexibility regarding where the front-seat passengers access the information. It can be argued that such flexibility can be provided by the combination of two displays (they can be used individually or together), or with the portable display that enables users to carry the information to anywhere. Finally, the portable display comes forward regarding its potential of being used as a means of input (e.g. tilting) like in the case of tangible user interfaces. In addition to these practical advantages listed in Figure 4.15, the reason why the fixed display in passenger dashboard was offered as transparent OLED was to let the passengers enjoy the look of the hand-crafted wooden panel even when they were dealing with the infotainment system.

4.3.2.3 Review of the design proposals with Bentley Motors HMI design team

The travel scenario, the infotainment features, the control and display alternatives for the front-seat passenger infotainment system which have been introduced in previous sections were also reviewed with the Bentley Motors HMI Design Team. The aim of the discussion was to: i) narrow down the scope of the travel scenario in terms of what front-seat passengers do (infotainment features), and ii) to select the most promising control and display alternatives to identify how they interact with the infotainment system. There were two main subjects kept in mind during the review of these design proposals: i) suitability of the design proposals to the 'Bentley experience' concept, and ii) the expected simulation challenges in interaction prototyping of the front-seat passenger infotainment system.

a. Review of the infotainment features

Table 4.12 presents the list of all infotainment features and the related discussions.

b. Review of the control alternatives

The discussions with the Bentley HMI Design Team mainly focused on the control alternatives which had been categorized by the VEC staff as "easy to deliver" for interaction prototyping with simulation in the focus group study. Therefore, the control alternatives presented in Figure 4.13 was shortlisted to eye-gaze recognition, gesture recognition and tangible user interfaces to be considered for the infotainment system design.

- **Eye-gaze recognition** was discussed as a promising technology as it made easier to track users' input. It eliminates the interaction tasks that are needed to identify the user interface element that user would like to interact with no matter which main input system it supports.

- It was mentioned that **gesture recognition** could be considered as an alternative only when it offered intuitive interactions. Lack of physicality (tangible input and output) raised concerns about communication of luxury, because it had always been defined through material qualities of the interior and controls. However, from aesthetics of interaction literature, we know that interaction aesthetics in general or the aesthetics of tangible interactions in particular is not only based on tactile aspects of interaction; there are spatio-temporal etc. aspects as well. In fact, it pointed out a research opportunity to investigate what aspects of gestural user interface were going to achieve or fail in terms of delivering the hedonic and pragmatic qualities in a luxury car.

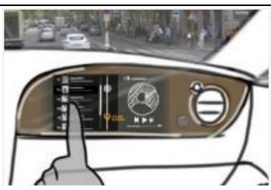
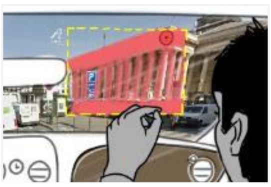
- **Tangible user interface** was also discussed as an alternative that could be considered for design development because it still offered a physical way to control the system and chance to apply haptic feedback (e.g. vibrations). Combination of the physical controller with the multi-functional knob was also discussed as a more versatile input solution.

c. Review of the Display Alternatives

During the discussions with the Bentley HMI Design Team **1. Head Up Display + Fixed Display (Transparent OLED)** and **2. Portable Display (Transparent OLED)** were prioritised over other alternatives because of their versatility which is also presented in Figure 4.15.

- **Head Up Display + Fixed Display (Transparent OLED):** Such combination enables division of information (e.g. using HUD for notifications while dealing with another menu function on the fixed display) and provides more than one alternative location for information provision.
- **Portable Display (Transparent OLED):** Through portability of transparent OLED display we can apply all augmented reality infotainment features for the side-window as well. Portability also offers alternative locations for information provision.

Table 4.12 List of Infotainment Features and comments of Bentley HMI design team

	**Receiving the journey plan sent by the driver** Since the journey plan might have been set before the day of the travel, the timing of the info-sharing among front-seat occupants was questioned.
	**Viewing the journey plan** Presentation of the key travel information in a less-complex way than standard navigation menus was appreciated. The advice was to enrich the information with the POIs within 'luxury network'.
	**Taking a photo of the view** Being able to take photos and save them with the other travel information were appreciated.
	**Tour Guide: POI / event suggestions** This feature was also highly praised as it can be enriched with the POI or event suggestions based on 'luxury network'.
	**Sending images from personal mobile devices** It was discussed if the car itself could take pictures of the car occupants and/or surroundings during stopover without bothering the users with sending information the car.
	**Reading (e-mail)** This was appreciated based on prevention of motion sickness, enlargement of the reading text, (compared to smart-phones) as well as provision of hands-free reading.
	**Listening to music & viewing playlist in relation to journey plan** Viewing and planning what to listen/watch based on journey plan was appreciated.
	**Doodling with AR brush** This feature was found more appropriate to back-seat passengers/children. Although it was proposed as an activity for traffic jam, the required time was raised as an issue. It was also suggested that the car could inform the user about the reason of the traffic jam rather than solely offering an entertainment feature.
	**Arrival - 'Approaching' Notifications** It was discussed that this feature could be utilised as a concierge service (e.g. welcoming from the hotel, indication of the VIP service) rather than just indicating the arrival to the destination.
	information entertainment communication

4.4 Design Detailing and Simulation Development

Based on the 'research through design' approach that the PhD research followed, the VR prototype of the front-seat passenger infotainment system design proposal was utilized to investigate in what ways the proposed functionalities and interactions affected front-seat passengers' travel experiences in a luxury car.

To gather data about the user experience of the infotainment system, it was important to enable the participants to experience the system in person within the context of travel. This research integrated VR to experience prototyping in a way that the participants were not only 'shown' the front-seat passenger infotainment system envisioned for the future Bentley GT, but they actively performed a list of infotainment tasks in an interactive and immersive way. Interactivity and immersion enabled the communication and discussion of the varied aspects of aesthetics of interaction (e.g. spatio-temporal, action-reaction) as well as the context (meta). In VR simulation the infotainment features and related interaction tasks were experienced within a travel scenario that included diverse spatial/temporal contexts.

The following sections will present the final design proposal for the front-seat passenger infotainment system that was prototyped with VR. The presentation of the design starts with the embodiment of the control and displays and the ways to perform basic interaction tasks. The section then follows with the travel scenario. The travel scenario involves several steps most of which introduce a new functionality (infotainment feature) for the front-seat passenger. Each step -that is referred as 'infotainment task'- includes a series of interaction tasks to be completed. Therefore, the section where travel scenario is presented also involves further details regarding the aesthetics of interaction. The introduction of the front-seat passenger infotainment system design will be followed by simulation development and the details of the user study-experience prototyping through simulation.

4.4.1 Front-Seat Passenger Infotainment System Design

Considering the review of ideas with the Bentley HMI Design Team, some infotainment features or tasks presented in the travel scenario (Figures 4.13, 4.14) were eliminated or combined for the final design proposal. The design proposal also underwent a final review with the VEC to understand if the interaction tasks pointed out in the final travel scenario and the varied control and display alternatives could be prototyped within the VEC facilities. As a conclusion of the reviews, a combination of head-up display and a fixed display (transparent OLED) was selected as the display (information provision) solution, a combination of hand gestures and a physical control with a touch sensitive surface was selected as the control solution of the system (See Figure 4.16).

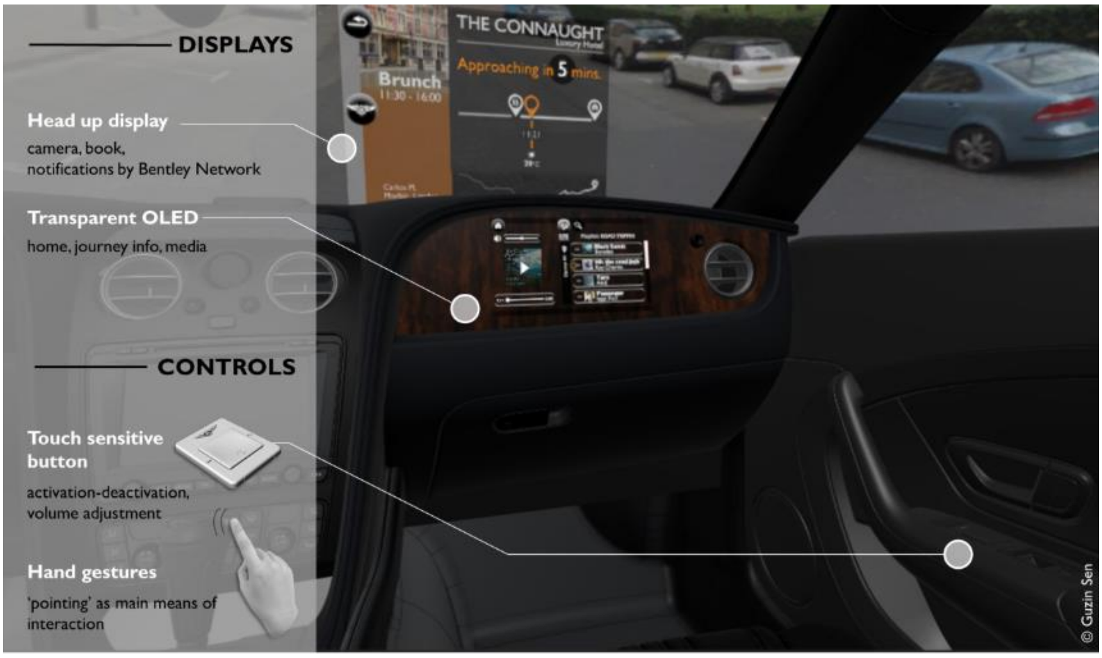


Figure 4.16 Displays and controls of the front-seat passenger infotainment system

Figure 4.16 shows the displays and controls of the front-seat passenger infotainment system. The following section will introduce the basic interaction tasks to be performed with the controls and displays provided in the system. However, to cover all details regarding the aesthetics of interaction, we need to refer to the ongoing communication between the passenger and the infotainment system. This communication will be presented as part of the travel scenario through the interaction tasks that need to be performed to enjoy a series of new functionalities (infotainment features) throughout the journey. In this thesis, the interaction aesthetics can only be communicated through still images; therefore, each interaction task is deconstructed into several consecutive images to present e.g. spatio-temporal and action-reaction aspects as much as possible.

4.4.1.1 The touch sensitive button

The system integrates a physical button with a touch sensitivity to perform basic tasks including activation/deactivation of the system and volume adjustment. It is located on the armrest, a 'ready-at-hand' location to perform these basic tasks comfortably and quickly. The infotainment system is activated and deactivated by pressing the button. The volume adjustment (which is also possible with hand gestures) is achieved by sliding /dragging the fingertip to the right (+) or left (-) on the touch sensitive surface (Figure 4.16).

4.4.1.2 Hand gestures: Pointing as the main means of interaction

The hand gestures work in a way that the system tracks the 'position and direction' of the pointing finger and process this information for the selection and activation of the interface elements. The tracking principle can be explained with the metaphor of an invisible stick that is attached to the tip of the pointing finger with which the user is touching the displays. It is possible to perform these pointing gestures while the user is resting his/her arm on the armrest; however, depending on the position of the interactive element, tracking performance can increase if the user adjusts the position of his/her hand accordingly. For activation of the selected interface element, the tracking system relies on the variable of 'duration of pointing'. For most of the functions, this duration was adjusted as 1.5 seconds to make sure that the user would like to activate the selected item.

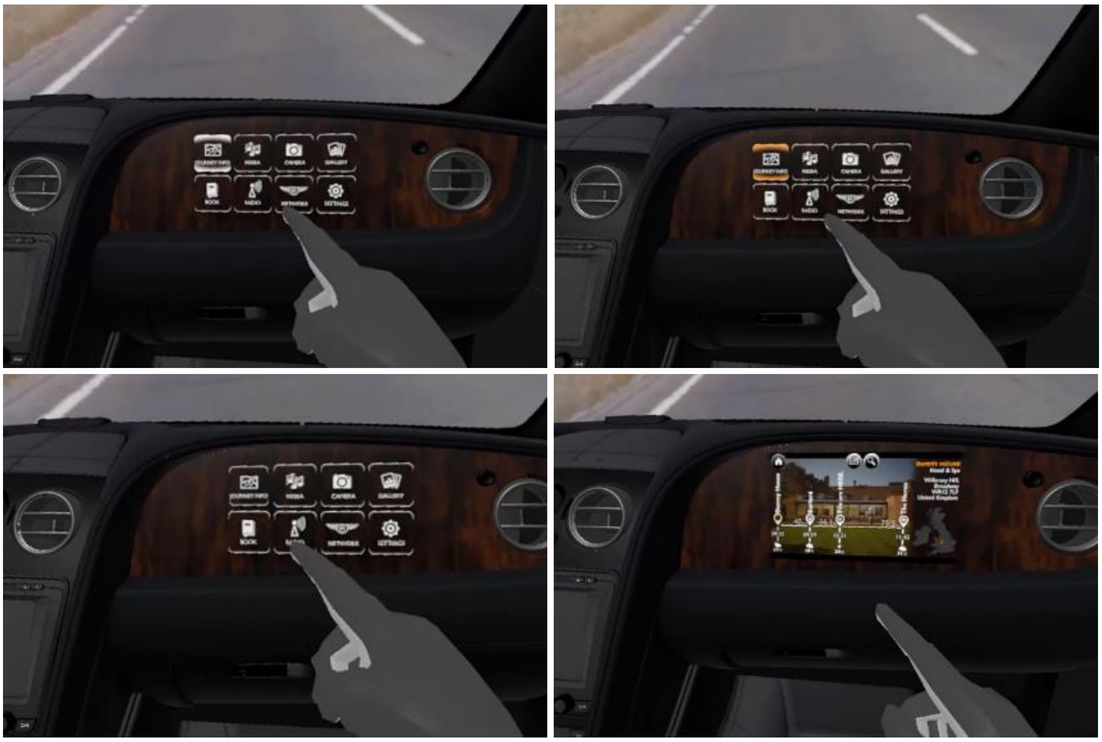


Figure 4.17 Selection and activation of the menu items in home menu

Figure 4.17 visualises this selection-activation process of the infotainment features in the main (home) menu. While selection is communicated with the white-coloured layer overlaid on the button, the duration of pointing that is required for the activation is communicated with the transition from the white layer to the orange layer. The final feedback for the activation of the menus is the animation of the menu button getting smaller, just before the selected infotainment menu appears on the transparent OLED or head-up display.

When it comes to scrolling or sliding the interface items, it is enough to point and move the pointing finger in vertical or horizontal axis. The feedback for the collision with the handle of the scroll bar/slider is also communicated with colour change from white to orange (See Figure 4.18).

Figure 4.18 Scrolling

The reasons for not identifying a specific gesture (e.g. waving hands to turn the page in book menu) for 'advancing' actions in this interaction design were i) not to force the users to remember or learn these specific gestures and ii) to keep the movement range of the gestures as minimum as possible to decrease the risk of driver's visual distraction. Another reason was the simulation-related limitations, since the tracking and identification of a specific hand gesture as an input and differentiation of this gesture from other hand movements constituted a more challenging programming task.

All infotainment menus (except the main/home menu with relatively larger interactive elements positioned next to each other) include a circular pointer/cursor, so that users can understand where they are pointing at and adjust the orientation of their hand/finger to interact with a specific interface element. Figure 4.19 shows the cursor at the left side of the head-up display menu. Thanks to its orange-coloured glow, it provides the necessary contrast with a variety of background colours that are used as part of the colour scheme of the GUI.

Figure 4.19 The cursor

4.4.1.3 Graphical User Interface (GUI)

Design detailing and visualisation of the GUI was handled in parallel to the simulation development. Therefore, the decisions regarding the GUI design, the source of the specific visual materials (e.g. photos) and the visualisation processes will be explained in detail in the 'Simulation Development' section. However, before presenting the GUI as part of the front-seat passenger infotainment system and the travel scenario; we should acknowledge that the colour scheme, the font, the button design and the menu icons are based on the graphical user interface design available in the latest models of the Bentley Motors automobiles. Aside from these basic visual materials and the graphical identity provided by Bentley Motors, the design of the layout of all infotainment menus, menu icons for the new infotainment features/functions and all other decisions regarding the visual content (e.g. size of the interface items; selection of photos, map style) belong to the author.

4.4.1.4 Travel Scenario

As mentioned earlier, the infotainment features and interactions will be presented as part of a travel scenario. The travel scenario is based on an existing route as can be seen from the screenshot of the Google Maps web page (2018) (Figure 4.20). The locations were selected according to the new infotainment features to be introduced during the journey, such as picturesque surroundings that are worth taking a photo with the camera feature. The demonstration of the front-seat passenger infotainment system through a travel scenario was not only significant in terms of associating specific functionalities with specific spatial contexts, the travel scenario also enabled us to introduce the functionalities that would be needed or make more sense in specific phases of the journey (e.g. while approaching to the destination); in other words, temporal contexts.

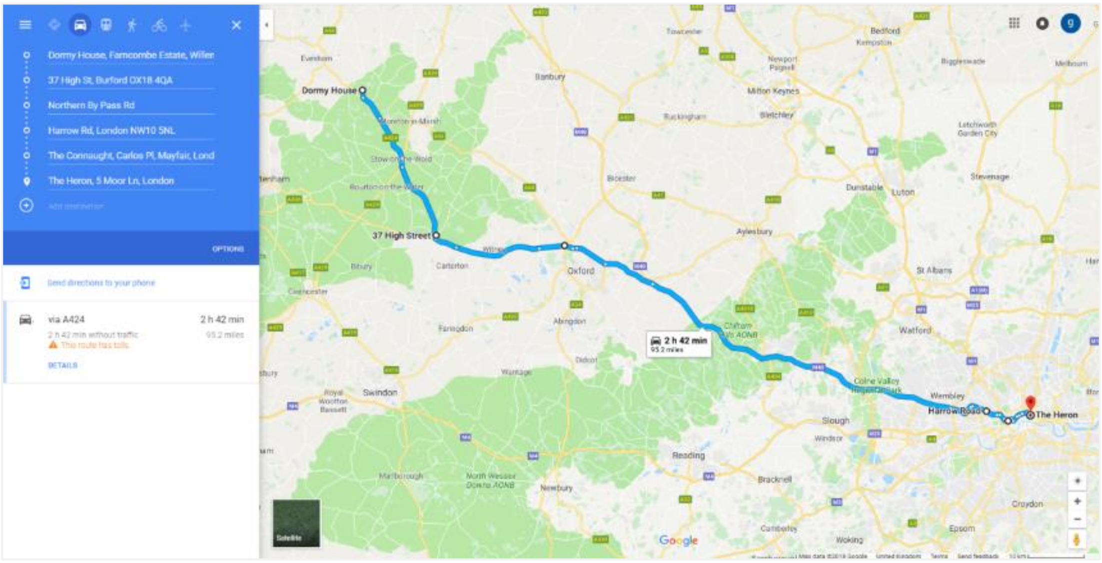


Figure 4.20 The existing journey route on which the travel scenario is based on (Google Maps, 2018)

Figure 4.21 demonstrates the list of locations and the infotainment menus (features) that the front-seat passenger is expected to deal with at these locations. The following section will introduce the infotainment features/tasks (from 1. Activation to 9. Deactivation) within the travel scenario together with the steps of interaction and the details regarding the varied aspects of aesthetics of interaction. For each infotainment task, the expected contributions of the new infotainment features (what the user interacts with) and interactions (how the user interacts with it) to the front-seat passenger's experience will be mentioned. Figures 4.22 and 4.23 compile all the relevant GUI visuals to communicate the series of interaction tasks performed within each infotainment menu feature in the same order they are experienced throughout the journey.

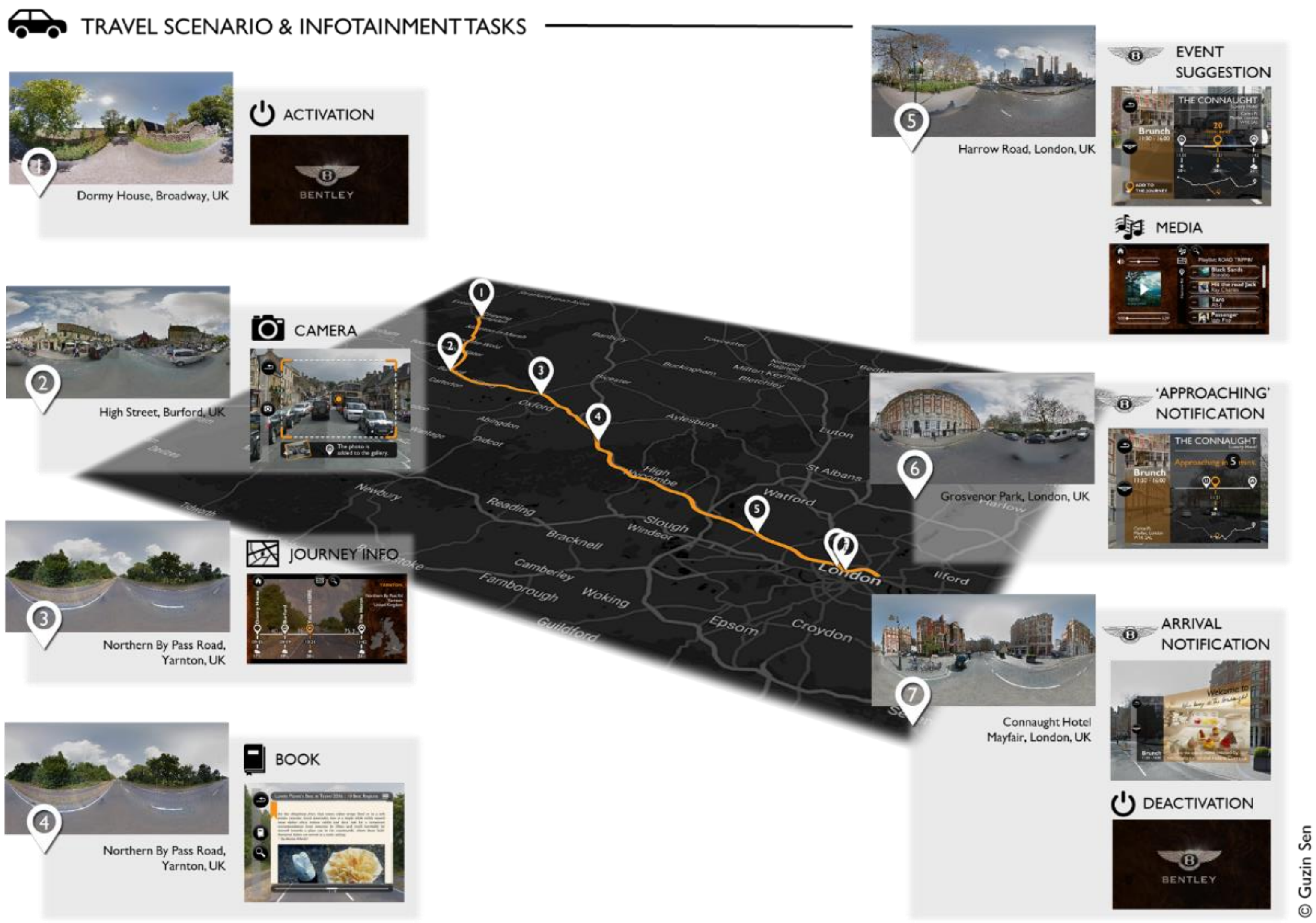


Figure 4.21 Travel scenario and infotainment tasks

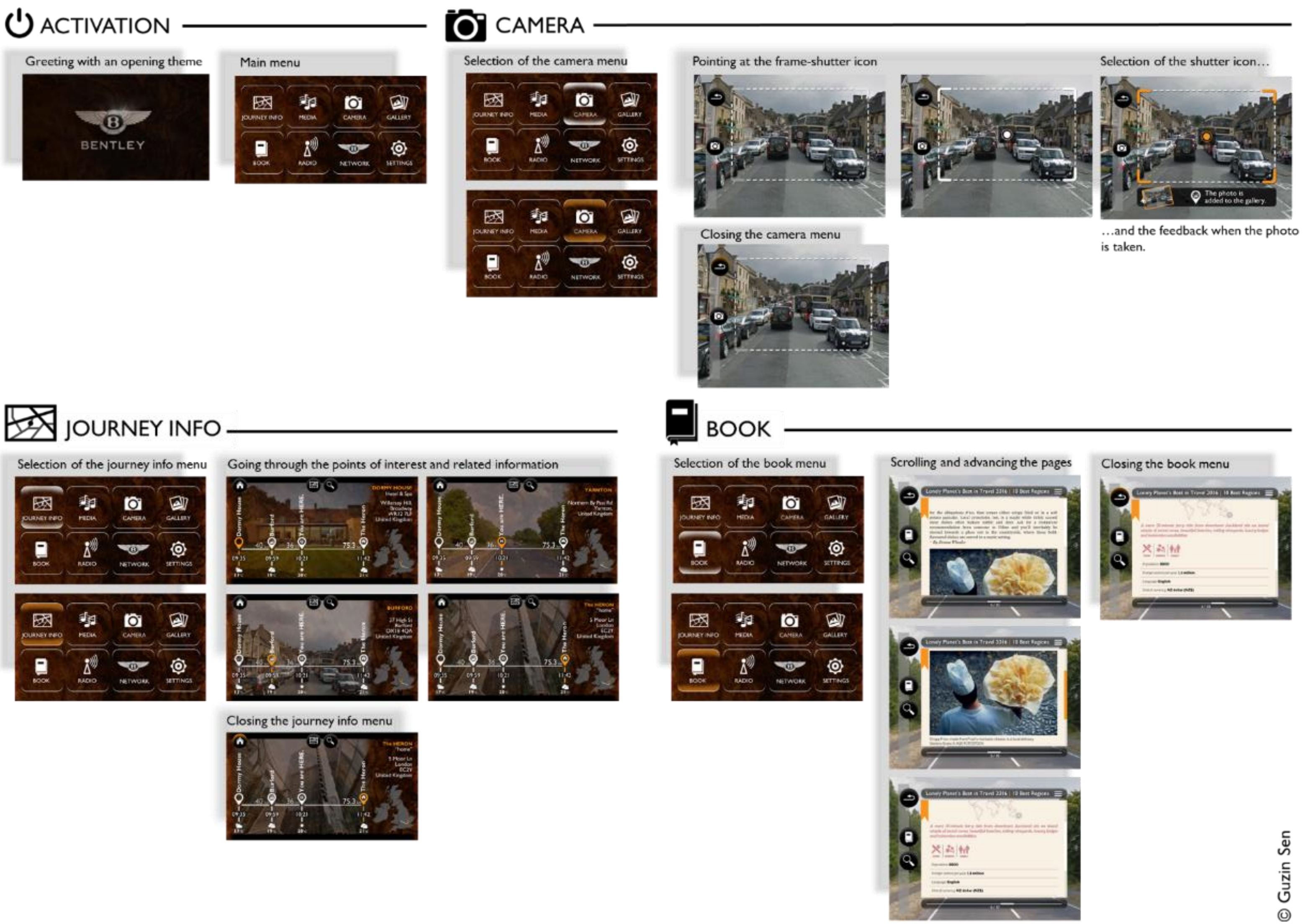


Figure 4.22 Infotainment features and interaction tasks-1

Figure 4.23 Infotainment features and interaction tasks-2

1. Activation

This travel scenario was planned as part of a weekend trip where Bentley GT users (the driver and the front-seat passenger) were taking a journey back home after a relaxing Saturday spent at the spa. The journey starts from a luxury spa-hotel "Dormy House" located in Cotswolds, Broadway, UK (Figure 4.24).

Figure 4.24 Starting point of the journey (Dormy House) and its view from the wind screen (Panorama image: Google Maps, 2016)

'The activation of the front-seat passenger infotainment system' involves the following interaction steps:

- The infotainment system is activated by pressing onto the button located on the armrest of the passenger door.
- The passenger is greeted by the system with an animation that includes the Bentley Motors logo (Figure 4.25).

Figure 4.25 A snapshot from the greeting animation on transparent OLED (The animation: Bentley Motors, 2015)

- After the animation fades out, the main/home menu (Figure 4.26) that consists of eight infotainment menu buttons appears.

In VR simulation, most of the menu buttons enabled the participants to access new infotainment features / content including *camera, journey info, book,* and *media*. Although it was not provided as an interactive menu option in the simulation, *Bentley Network* button was planned to access the notification of event / venue suggestions provided by the Bentley Network App from head-up display throughout the journey. The rest of the infotainment menu buttons; *gallery, settings* and *radio* were added to represent other default functionalities, but not included in the simulation either.

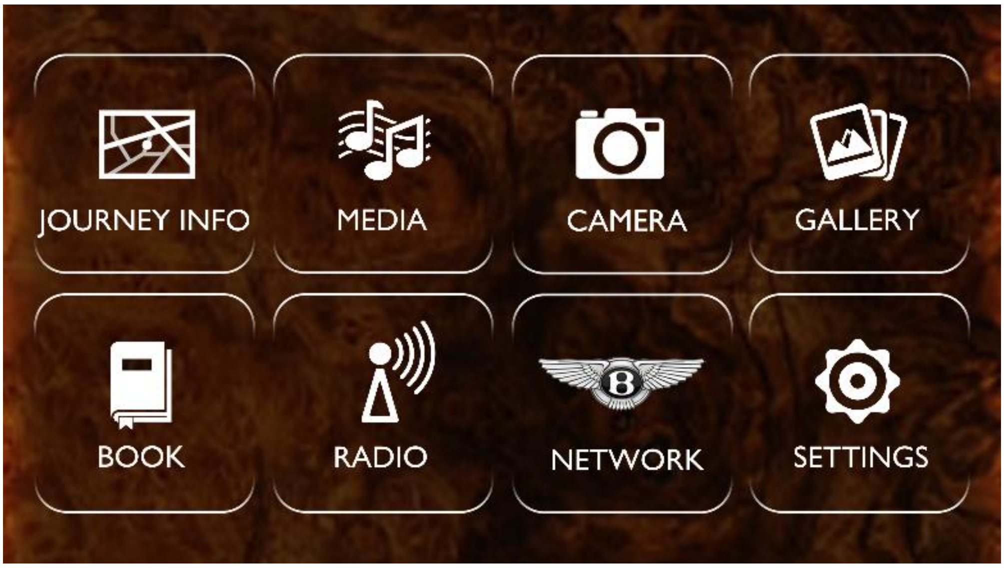


Figure 4.26 Main (Home Menu)

Motivations behind the design decisions regarding functionality and aesthetics of interaction

As mentioned earlier in the initial travel scenario proposal, the addition of a greeting animation with the luxury 'content' (Bentley Motors logo) was expected to reproduce 'the symbolic value' of the brand by reminding the passenger that he/she is about to enjoy a journey in Bentley Continental GT. The animation of the sparkling Bentley Motors logo (Figure 4.25) includes a material effect that we usually observe in precious metals or crystals, which again reproduces the luxury meaning associated with these materials. The activation of the infotainment system points out a transition from the current to another state involving new functionalities and interactions. Therefore, for this greeting ritual, an animation rather than a still image was preferred to attract the attention of the front-seat passenger for a duration of time. In addition to the greeting animation with Bentley Motors logo, the context of interaction (departure from a luxury hotel) was also expected to influence the experience of the activation task via its symbolic luxury value.

2. Camera

The journey continues with arrival at another location, a historical town in Burford, UK (Figure 4.27). This picturesque location was selected as a relevant spatial context to utilize ‘camera’ feature.

Figure 4.27 High St, Burford, UK and the view through the wind screen (Panorama Image: Google Maps, 2016)

In the camera feature, head-up display is utilized as the viewfinder and the digital frame on the head-up display defines the cropping borders of the image taken by 180/360-degree cameras of the car. ‘Taking a photograph of the surroundings of the car through the camera menu in head-up display’ involves the following interaction steps:

- Selection and activation of the camera menu by pointing at the camera button for 1.5 seconds until the white-coloured layer turns orange (Figure 4.28).

Figure 4.28 Selection and activation of the camera menu

- Pointing at the shutter icon in the middle, which is confirmed by the system through increase in opaqueness of the frame’s corners and the shutter icon (Figure 4.29).

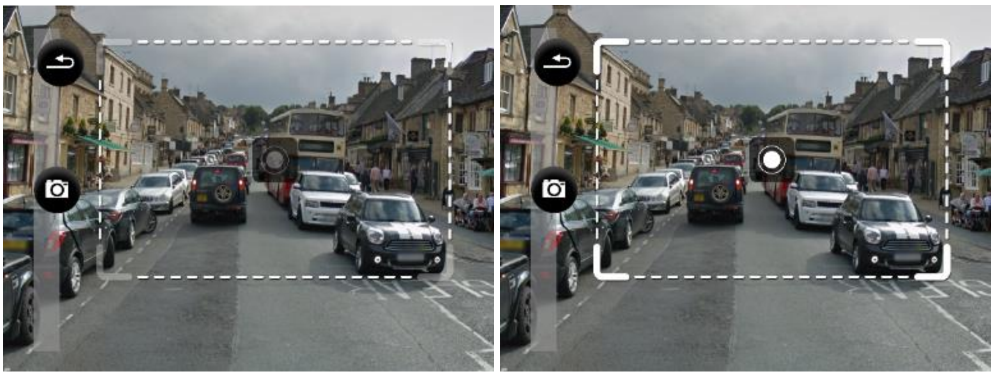


Figure 4.29 Confirmation for pointing at the frame

- Taking the photo by pointing at the shutter icon until its colour turns orange. The feedback - *the photo is added to the gallery*- is provided under the frame, it includes the thumbnail of the photo and the confirmation of the geo-tagging (Figure 4.30).

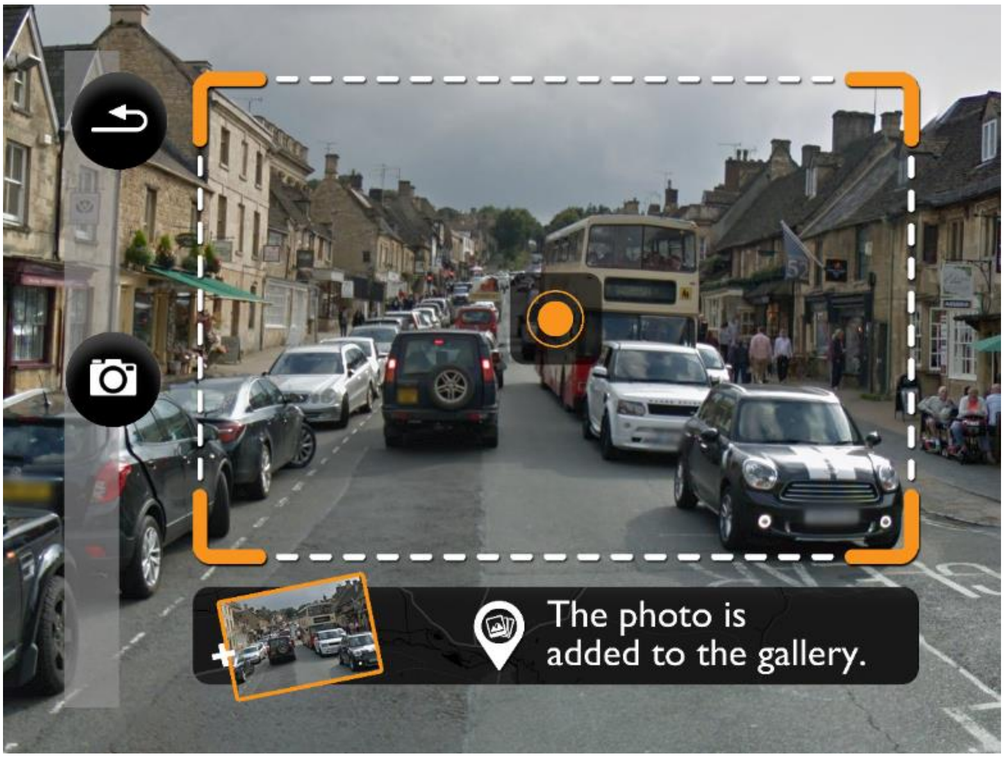


Figure 4.30 Taking the photo

- Closing the camera menu by pointing at the 'back' button (Figure 4.31).

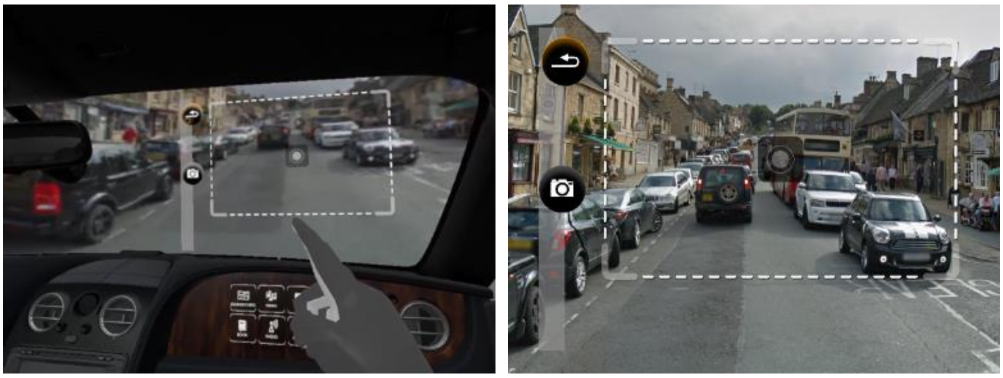


Figure 4.31 Closing the camera menu

Motivations behind the design decisions regarding functionality and aesthetics of interaction

This feature was added as means of *stimulation* to make front-seat passengers more engaged in the journey through recording the journey with novel means of interaction. It was also expected to contribute to *evocation* by provoking memories of that unique journey in the longer term. This feature was preferred to be delivered via head-up display to provide front-seat passengers with a more direct presentation, as if they were grabbing an image out of their windscreen view to tag specific location on the map with that image.

3. Journey Info

The journey continues with entrance to a highway road, which is Northern by Pass Road, around Yarnton, UK. As can be seen in Figure 4.32, there is not enough clue in the environment regarding where the car is now or how much time is left for the arrival to the next destination. This may require referring to other means of information, which, in this travel scenario, is the “journey info” menu in the front-seat passenger infotainment system.

Figure 4.32 Northern by Pass Road, Yarnton, UK and the view through the windscreen (Panorama Image: Google Maps, 2016)

‘Viewing journey info’ feature involves the following interaction steps:

- Selection and activation of the journey info menu by pointing at the journey info button for 1.5 seconds until the white-coloured layer turns orange (Figure 4.33).

Figure 4.33 Selection and activation of the journey info menu

- Going through each destination point on the journey line by pointing at it (See Figure 4.34). Unlike the pointing duration required for the activation of the menus, in this menu, the relevant information is presented as soon as the user points at the destination since there is nothing to activate. For each destination, the front-seat passenger can view the address, it's location on the map, arrival time, weather forecast, distance travelled until that destination, distance left to the next destination and a representative background picture (Figures 4.35, 4.36, 4.37 and 4.38), which can be personalized with the geo-tagged photos taken during the journey (or past journeys) as in Figure 4.36.

Figure 4.34 Going through each destination point on the journey line by pointing at it

Figure 4.35 Journey Info-Dormy House

Figure 4.36 Journey Info-Burford

Figure 4.37 Journey Info-Yarnton

Figure 4.38 Journey Info-Heron

- Returning to main/ home menu by pointing at home button (Figure 4.39)

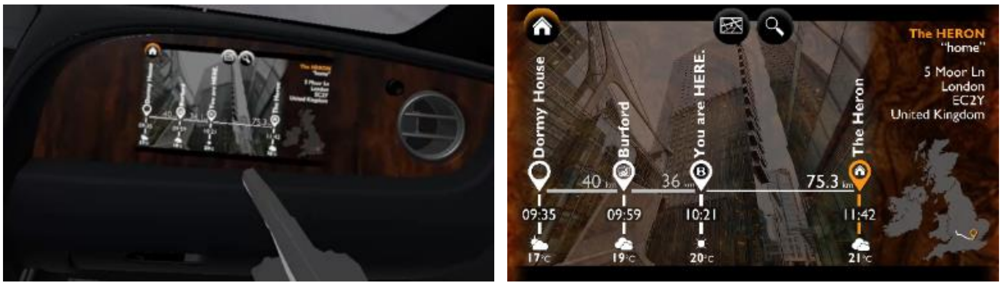


Figure 4.39 Returning to main/ home menu

Motivations behind the design decisions regarding functionality and aesthetics of interaction

This feature was expected contribute to the experience of the front-seat passenger in several ways. In terms of *functional/pragmatic quality* it was expected to increase the *competence and control* of the passengers by enabling them to access all the key information about the travel and make plans about what to do in following phases of the journey. Through the record of the travel history with addition of geo-tagged photos and destination points, passengers can reflect on the earlier phases of that specific journey or the past travelling experiences, which also enables customisation of the information presentation with the content created by the front-seat passengers (*evocation*).

4. Book

The car occupants are still travelling on Northern by Pass Road, Yarnton, UK (Figure 4.40). Having seen in the journey info menu that there is still time to arrive in the next destination, the front-seat passengers may want to make use of one the stimulation options provided in the infotainment menu; such as book.

Figure 4.40 Northern by Pass Road, Yarnton, UK and the book menu provided on the head-up display (Panorama Image: Google Maps, 2016)

Book is one of the infotainment features provided through head-up display. 'Reading a book' feature involves the following interaction steps:

- Selection and activation of the book menu by pointing at the journey info button for 1.5 seconds until the white-coloured layer turns orange (Figure 4.41).

Figure 4.41 Selection and activation of the book menu

- Scrolling through the page with the scroll bar on the right and skipping to other pages by using slider at the bottom. As mentioned earlier, scrolling/sliding actions is performed by pointing at the handle of the scrollbar / slider and moving the pointing finger in vertical / horizontal axis. The feedback for the collision with the handle of the scroll bar / slider is also communicated with colour change from white to orange (Figure 4.42).

Figure 4.42 Scrolling through and advancing the pages

- Closing the book menu by pointing at the ‘back’ button (Figure 4.43).

Figure 4.43 Closing the book menu

Motivations behind the design decisions regarding functionality and aesthetics of interaction

The contribution of this infotainment feature to user experience of front-seat passengers may vary depending on the content of the reading material, however it is expected to be another source of *stimulation* during the journey. This functionality is included in this travel scenario to explore if the utilization of head-up display (e.g. bigger pages or fonts to increase readability, more comfortable reading posture) would contribute to the functional/pragmatic value of the experience.

5. Event Suggestion

The journey continues with arrival in London, the current location of the car is Harrow Road. It is the location where event suggestion by Bentley Network application is provided.

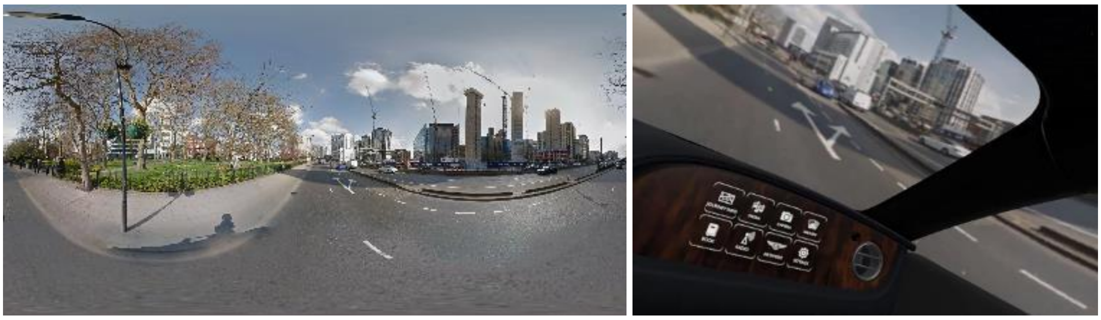


Figure 4.44 Harrow Road, London, UK and the view through the wind screen (Panorama Image: Google Maps, 2017)

'Event suggestion' feature involves the following interaction steps:

- Presentation of the suggestion as a notification that pops up on head-up display. Although we use the term 'pop-up', the notification does not suddenly appear on the head-up display. The provision of the notification includes a transition animation with the menu growing bigger as can be seen in Figure 4.45. The notification includes another animation where the related information about the location of the event fades in and gets bigger to attract the front-seat passenger's attention (the image on the right in Figure 4.45).

Figure 4.45 Appearance of the event suggestion notification on HUD

In this scenario, the event suggestion was decided to be a brunch event which takes place in a luxury hotel "The Connaught" in Mayfair area, London, UK. The notification includes the time and location of the brunch event, a map on the below with the current route and demonstration of how this route would change if the user adds this event to the journey plan. It also presents the remaining destinations and time in the same format presented in journey info menu, so that the front-seat passenger and other car occupants can decide by reviewing the key journey information (Figure 4.46).

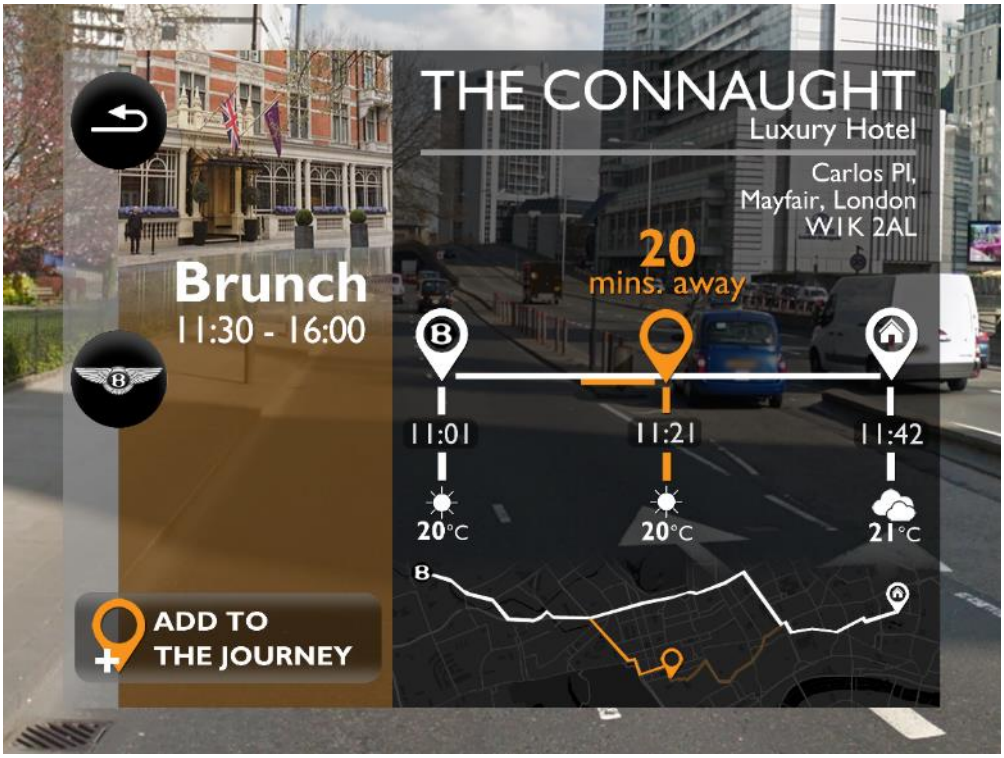


Figure 4.46 Event suggestion

- Adding the related destination to the journey by pointing at the button on the left. The feedback is provided with the change in the statement from add to journey to added to journey as well as the change in the colour of the button from white to orange (Figure 4.47).

Figure 4.47 Adding the related destination to the journey

- Closing the notification by pointing at the ‘back’ button (Figure 4.48).

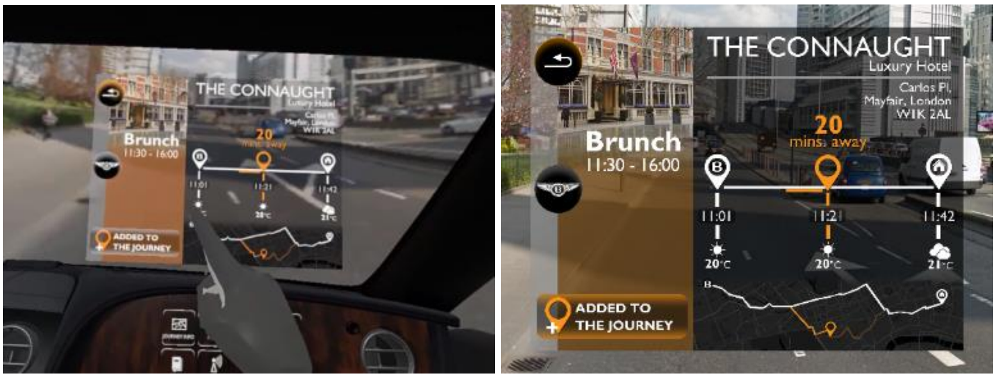


Figure 4.48 Closing the notification

Motivations behind the design decisions regarding functionality and aesthetics of interaction

This infotainment feature was added as another functionality to support the idea of ‘luxury of spontaneity’. These suggestions were expected to be a source of *stimulation* for front-seat passengers by keeping them engaged in the journey through the surroundings information and by enabling them to discover new places/events. Accessing to such customised information and making discoveries would make front-seat passengers feel more *competent* and *in control* and contribute to their *self-actualization.* Another contribution of this feature to user experience was considered as *identification (popularity, relatedness* to the community of Bentley Motors users), since the suggestion was thought to be provided to other Bentley Network members as well.

Regarding the aesthetics of interaction, provision of this suggestion as a pop-up notification on head-up display was considered as a *stimulating* form of interaction. However, not to cause any negatively unpredictable experience, the transition animations were added; so that the users could still feel *in control*. Utilization of head-up display was considered to enable the front-seat passenger to continue dealing with the menu features provided on transparent OLED display in an *efficient* way (functional value/pragmatic quality-manipulation)

6. Media

The car occupants are still travelling on Harrow Road, London, UK (Figure 4.49). Having been informed that there are 20 minutes left to arrive in Connaught Hotel for the brunch event, the front-seat passenger may prefer making use of this remaining time to listen to a few songs.

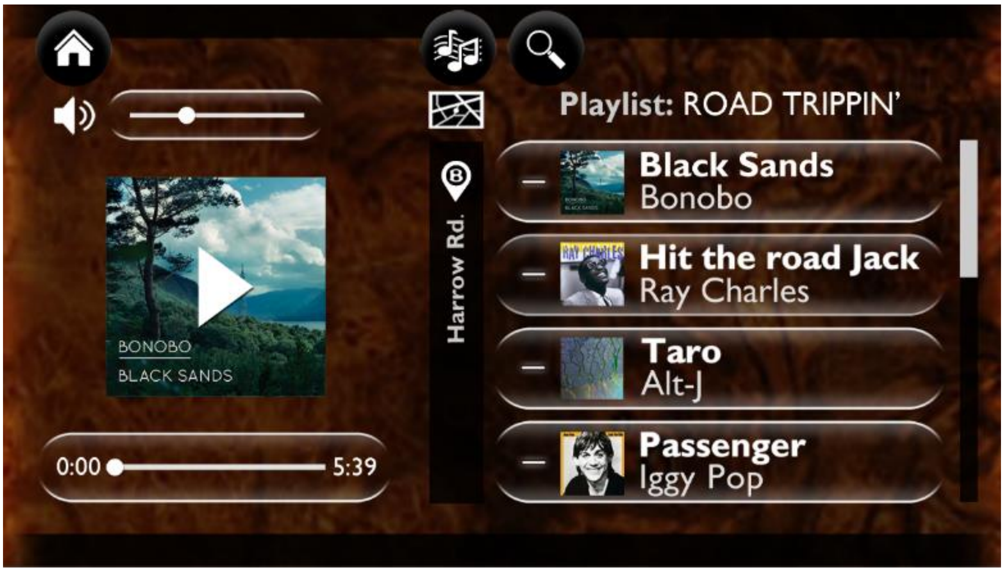
Figure 4.49 Harrow Road, London, UK (Panorama Image: Google Maps, 2017)

'Listening to music' feature involves the following interaction steps:

- Selection and activation of the media menu by pointing at the journey info button for 1.5 seconds until the white-coloured layer turns orange (Figure 4.50).

Figure 4.50 Selection and activation of the media menu

- Scrolling down on the playlist on the right. The action-reaction aspects of scrolling-sliding interactions in previously mentioned menus also apply to the scrollbar in the media menu. By scrolling through the playlist, the front-seat passenger can also see which song will be playing when they arrive at the hotel with the pin attached to the left side of the song. (See the text "The Connaught" next to the song 'Crosses' by Jose Gonzalez in Figure 4.51.)



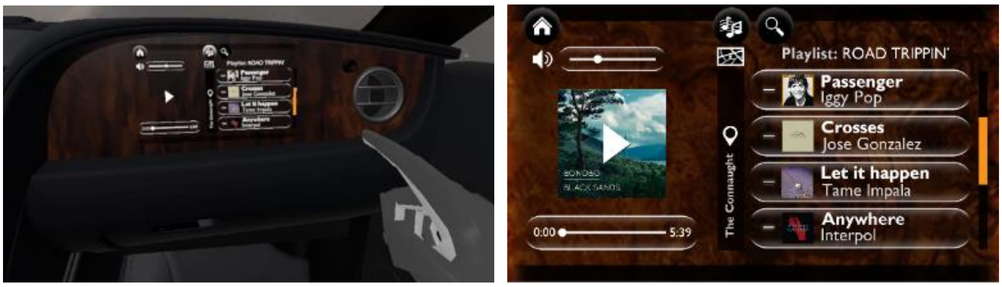


Figure 4.51 Scrolling down the song list

- Selecting and playing song and pointing at the song button for 1.5 seconds until the white-coloured layer turns orange (Figure 4.52).

Figure 4.52 Selecting and playing song

- Adjusting the volume by pointing at the handle of slider and moving the pointing finger in horizontal axis (Figure 4.53). The volume can also be adjusted by sliding / dragging the fingertip to the right (+) or left (-) on the touch sensitive surface of the button on the armrest.

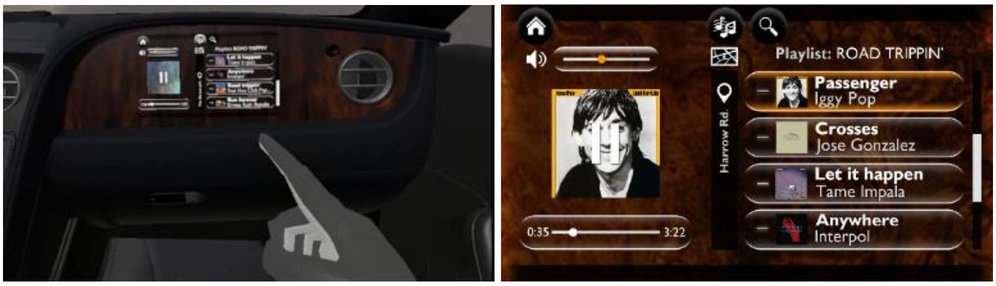


Figure 4.53 Adjusting the volume

Motivations behind the design decisions regarding functionality and aesthetics of interaction

Media players have been the default entertainment features provided in infotainment systems. However, this feature did not only make the media player more accessible to front-seat passenger, but it also differed from other media players by creating a bond between the means of *stimulation* and the journey itself.

7. ‘Approaching’ Notification

The front-seat passenger infotainment system design proposed that the car was going to notify the front-seat passenger when there were 5 minutes left to arrive in a set location. According to the travel scenario and the route, the location where this notification is provided is Grosvenor Park, Mayfair, London, UK as can be seen in Figure 4.54.

Figure 4.54 Grosvenor Park, Mayfair, London, UK and the view through the wind screen (Panorama Image: Google Maps, 2017)

‘Receiving the notification that the car is approaching to the destination’ involves the following interaction steps:

- Appearance of the notification on the head-up display with a transition animation of the menu growing bigger as can be seen in Figure 4.55. The notification includes another animation where the text “Approaching in 5 minutes” fades in and gets bigger to attract the front-seat passenger’s attention to the key message.

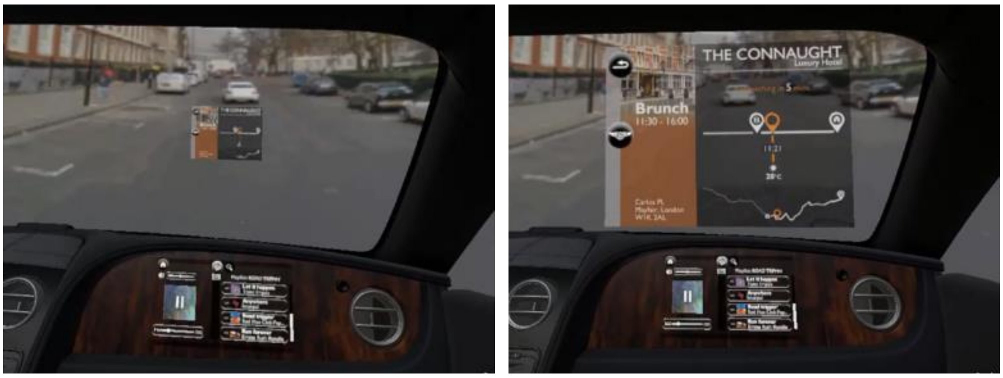


Figure 4.55 Appearance of the ’approaching’ notification

As in the event suggestion, this notification also includes a map where the current location of the car and the destination where the car is approaching (e.g is the Connaught Hotel in the example screenshot). It refers to the visual format used in journey info menu that includes the time of arrival and expected outside temperature for that destination (Figure 4.56).

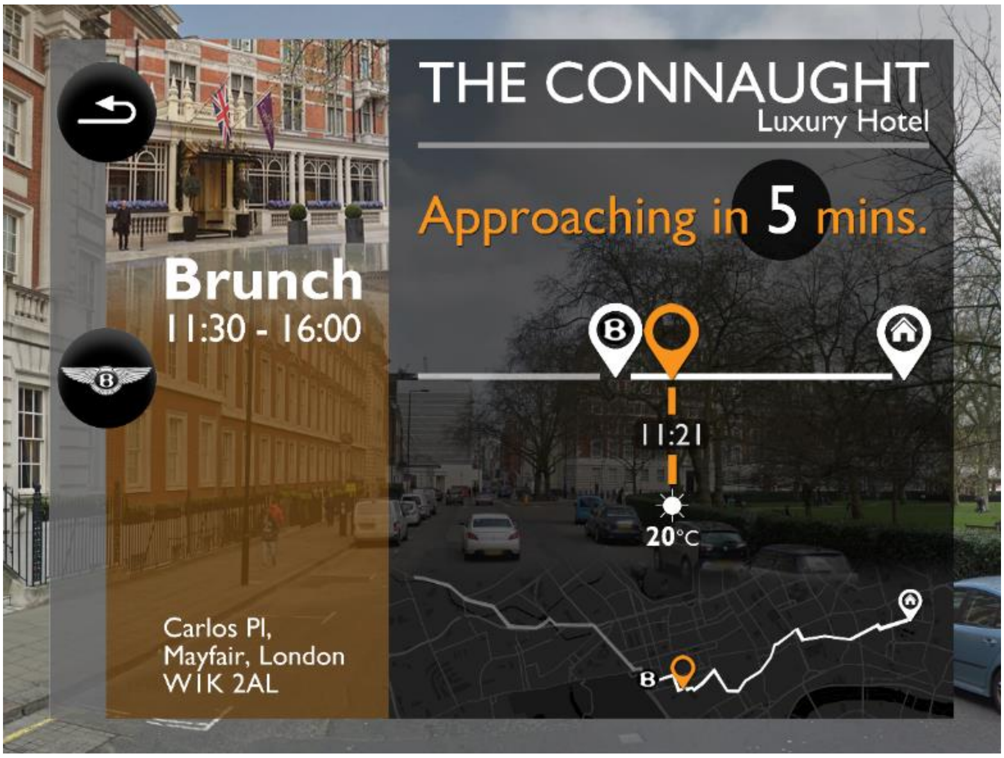


Figure 4.56 The ‘Approaching’ notification

- Closing the menu by pointing at the ‘back’ button (Figure 4.57).

Figure 4.57 Closing the ‘approaching’ notification

The notification provides the necessary time for the front-seat passenger to get ready for alighting (getting of the car). The remaining tasks include turning the music off and going back to home menu as presented in the following steps:

- Pointing at the album cover on the left for 1.5 seconds until the white-coloured pause icon turns orange (Figure 4.58).

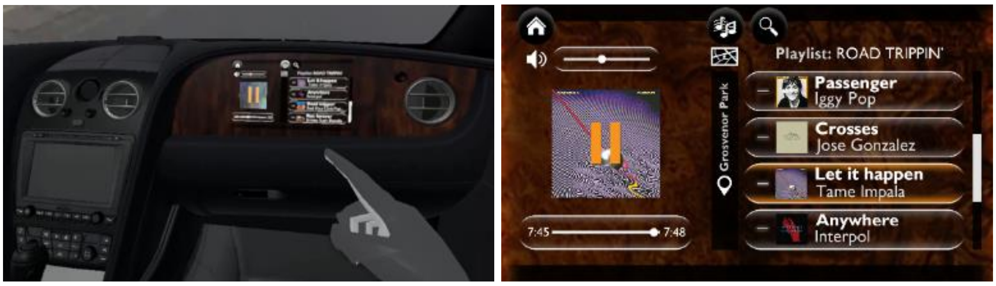


Figure 4.58 The pause

- Returning to main/ home menu by pointing at Home button.

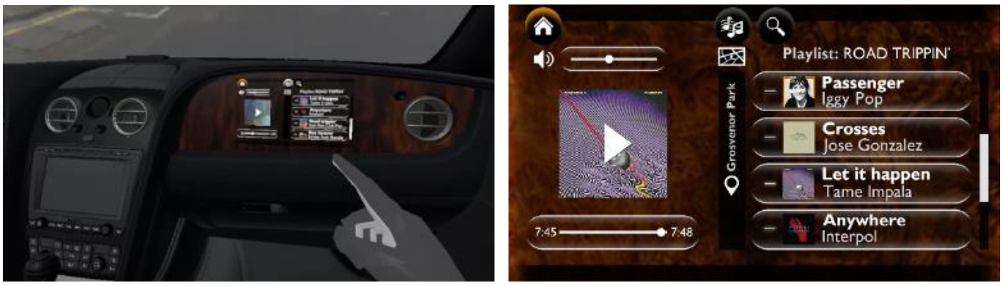


Figure 4.59 Returning to main/ home menu from the media menu

Motivations behind the design decisions regarding functionality and aesthetics of interaction

As in the previous information features (e.g. journey info), receiving the information that 'the car is approaching to the stopover soon' was also expected to make front-seat passenger feel more *competent* and *in-control*. This was not only because of accessing key information about the journey but also having an adequate time to get ready for the arrival. This feature was offered to automatically answer the "Are we there yet?" question that would have otherwise been asked to the driver or checked through the location services of other devices. Satisfaction of such anticipation (or the anticipation of the fact that the car will notify the user) was also expected to contribute to *autonomy* of the front-seat passengers.

8. Arrival Notification

The car arrives in the Connaught Hotel, Mayfair, London, UK (Figure 4.60) and notifies the front-seat passenger about the arrival through the head-up display. Since the point of interest is the location of the event suggested by Bentley Network application, this notification is also provided as part of Bentley Network Application. This feature is not only an indication of the arrival but also a greeting by the hotel.

Figure 4.60 The Connaught Hotel, Mayfair, London, UK and the view through the wind screen (Panorama Image: Google Maps, 2017)

'Arrival notification' feature involves the following interaction steps:

- Appearance of the notification on the head-up display with a transition animation of the menu growing bigger in time. This animation also incorporates the direction (as an aspect of interaction) in a way that the menu moves from the hotel towards the passenger since it is a greeting message sent from the hotel (Figure 4.61).

Figure 4.61 Appearance of the arrival notification on HUD

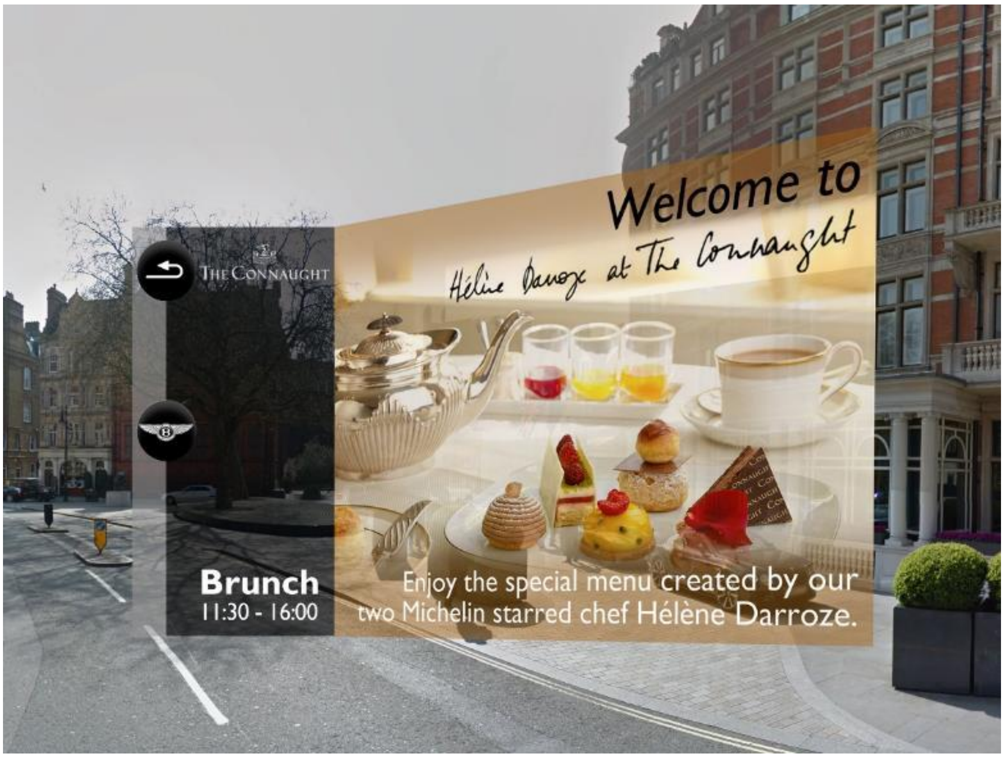


Figure 4.62 Arrival notification

The content of the notification is expected to vary depending on the arrival location. In this travel scenario, the hotel is where the suggested brunch event is taking place. Therefore, the glimpse of the brunch menu is presented in this greeting message to show what is waiting for the car occupants in this Michelin starred restaurant “Helene Darroze at The Connaught” (Figure 4.62).

- Closing the arrival notification by pointing at the ‘back’ button (Figure 4.63).

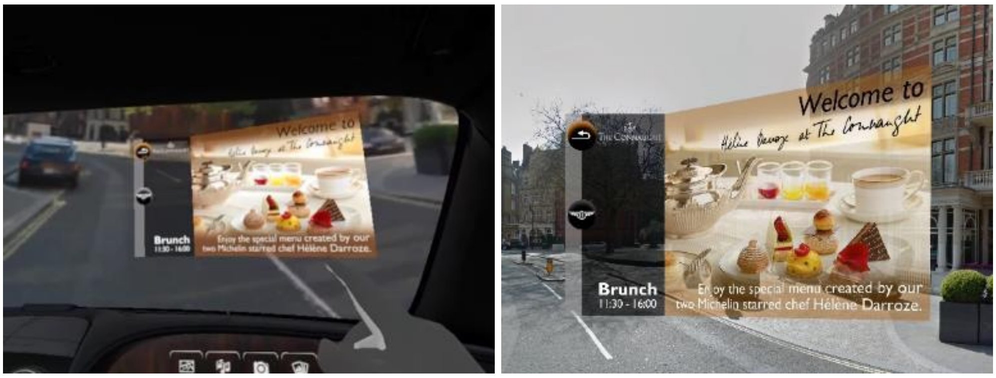


Figure 4.63 Closing the arrival notification

Motivations behind the design decisions regarding functionality and aesthetics of interaction

This infotainment feature was considered as a celebration of the arrival to a location, in other words, as a way to enhance the competence driven from completion of the ‘passengering’ task. Therefore, it presented a stimulating way of providing this journey related information by taking advantage of augmented reality and animation. In terms of its functional value, as in other information features, the passengers were expected to feel more in-control through the confirmation of the arrival, indication of the arrival location as well as the information about the event held at that location. In cases where this notification was provided by the venues within the Bentley Network, this feature was also considered to give a chance to the host venue (in this case: the Connaught Hotel) to welcome its customers and extend its luxury service to the inside of the car.

9. Deactivation

Before alighting the car to enjoy the brunch at the Connaught Hotel the passenger deactivates the front-seat system through the following interaction steps:

- pressing the button on the armrest,
- appearance of the animation with the Bentley Motors logo.

Motivations behind the design decisions regarding functionality and aesthetics of interaction:

The de-activation was more of a task to be completed rather than a new functionality. However, as mentioned earlier, the animation was considered as a visual way for the car to say, “until next time” and as a reminder of the symbolic value of the journey through the Bentley Motors logo.

4.4.2 Simulation Development

This section presents the development of the virtual reality simulation of the front-seat passenger infotainment system interactions and experience by referring to the previously mentioned travel scenario, functionalities and interactions. It first discusses the decisions regarding what dimensions of the front-seat passenger infotainment system are prototyped (what to prototype) and how they are prototyped (scope, medium and fidelity of the simulation). Then it presents the simulation development and design detailing processes, which include visualisation, programming of the interactions and preparation of the physical setting.

4.4.2.1 Prototyping (related) decisions

a. What is prototyped

This section describes what is prototyped regarding the front-seat passenger infotainment system by referring to a set of ‘filtering dimensions’ (Lim et.al, 2007). In the PhD research, they were redefined according to the *what* and *how* dimensions of interacting with technology (Hassenzahl, 2010). Therefore, regarding “what to prototype”, the filtering dimensions for the VR simulation of the front-seat passenger system can be listed as:

- The what of the front-seat passenger infotainment system:
    - functionality
    - content
- The how of the front-seat passenger infotainment system / aesthetics of interaction:
    - sensory-specific aspects (visual, audio, haptic, kinesthetic aspects)
    - spatio-temporal aspects
    - action-reaction aspects
    - presentation aspects

- The context (meta)

Design detailing and the simulation development processes were carried out simultaneously. Therefore, what was presented as the front-seat passenger infotainment system design in previous sections also demonstrated the scope of what was prototyped with VR simulation. However, in this section, design decisions are deconstructed based on the above-mentioned filtering dimensions. This is to define scope, medium and fidelity of the prototype (manifestation dimensions by Lim et. al, 2007) for each aspect of interactive system.

b. Scope

Scope of prototype based on functionalities (infotainment features & tasks) and content:

This section presents the scope of the prototype regarding the functionalities and the content. As the aim was to prototype the front-seat passenger infotainment system design, the term functionality refers to the infotainment features (e.g. camera: taking a photo) and the interaction steps that need to be followed to achieve the infotainment task (e.g. activation of the system, selection of shutter icon in camera menu). On the other hand, the term content refers to any kind of information the system communicates to the user.

The main reasons behind the narrowing down the scope of the functionalities included in the prototype are as follows:

- **The aim and the scope of the research:** The main aim of the prototyping was to introduce new infotainment features or to introduce novel ways of executing the default infotainment features. The aim of the prototyping (and design) was not to demonstrate all possibilities regarding the interaction flow within the information architecture.

  The flow of interaction presented in the simulation can be considered as a few branches of the overall interaction flow that would have been designed if the infotainment system were to be manufactured. This also constituted the reason why the participants were guided during simulation in terms of what to do next instead of letting them explore every interface element anytime they want. In this research, the interaction steps concentrated on delivering the main tasks (e.g. taking the photo, reading a book) rather than supporting tasks (e.g. sharing it in social media, browsing the library) of a specific functionality. The advantage of such limitation was providing more space for participants to comment on the expansion/enrichment possibilities of the infotainment features in the user study. Although it is not directly related with the functionalities, selected interaction steps for the infotainment features were also versatile enough to enable the participants of the user study to evaluate and comment on the aesthetics of interaction of the infotainment system.

- **Duration of the simulation and the user study:** The number of interaction steps were kept to a minimum for each infotainment feature. This was to lessen the duration of simulation, hence to avoid simulator sickness, and to limit the session length with one hour.

- **Optimisation of the simulation development process:** The number and the variety of the interaction tasks to be programmed were kept to a minimum to complete the simulation development on time.

The main reasons behind narrowing down the scope of the *content (information)* involved in the functionalities are as follows:

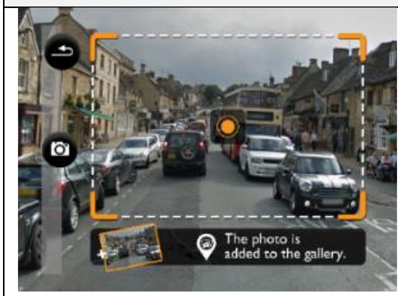
- **Narrowing down the scope of the functionalities**: Prototyping fewer interaction tasks means demonstration of less content.

- **Limitations of the simulation hardware/software:** Considering the front-seat passengers' field of view, the displays of the user interface constitute a small area within the entire car interior. Since it was not possible for our eyes to adjust the depth of field in what we see in head-mounted display (the depth is not physical but virtual), the GUI could not be provided as sharp as it could be in a real car. The solution to this limitation was found in having fewer but larger visual content in each menu and using bigger fonts, which in return lessened both the variety and the amount of information. This eventually eliminated the interaction tasks that were related with the removed content such as viewing the comments about the suggested venue in event suggestion. Regarding the limitations of simulation hardware/software, another concern was the size of the files, which limited the amount of the specific content such as the MP3 song files in the media menu.

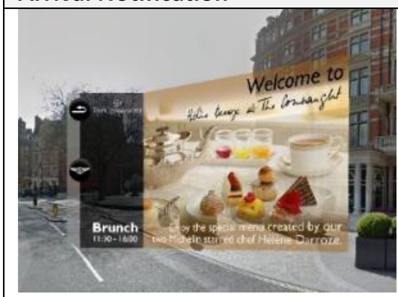
These limitations were also pointed out by the participants as the limitations of the infotainment system design in user experience evaluation, however, they did not affect the delivery or appraisal of other functionalities through prototyping.

Table 4.13 demonstrates the scope of the functionalities and the related content that were delivered via prototype. The eliminated interaction tasks for each functionality are written in 'grey'.

Table 4.13 Scope of Prototype based on Functionalities (Infotainment Features & Tasks) and Content

Activation	
 	**Scope of the simulation based on functionality:** • Pressing the button to activate the system • Being greeted with an animation • Viewing the home/main menu **Scope of the simulation based on content:** The animation did not involve any audio content neither in the design nor in the simulation of the design. The home menu was limited with 8 menu buttons. They included the features that were utilized in the user study (journey info, media, camera, book); features that were related with these features (gallery, network); as well as a few default features (settings, radio) to have 8 square buttons on TOLED display with the aspect ratio of 16:9.
Camera	
	**Scope of the simulation based on functionality:** • Selection and activation of the camera menu • e.g. Changing the frame size (zooming in/out) and position • Pointing at the shutter icon to take a photo • Activation of the shutter and receipt of the feedback that the photo is added to the gallery. • e.g. Viewing the gallery together with other geo-tagged photos • e.g. Sharing the photo through connected social media applications • Closing the camera menu **Scope of the simulation based on content:** The camera feature was asked to be used in a specific location for once; so, the action of taking a photo and the content provided in feedback was limited with one picture.

<table>
<tr><th colspan="2">Journey Info</th></tr>
<tr><td rowspan="2">
</td>
<td>Scope of the simulation based on functionality:
Selection and activation of the journey info menu
Going through the points of interest and viewing related information
e.g. Reading further information about the point of interest (history, visitor reviews, interesting facts)
e.g. Zooming into the route/map on the right
e.g. Browsing and adding new points of interest
Going back to home menu</td></tr>
<tr><td>Scope of the simulation based on content:
The number of points of interests, so the amount of information was kept minimum: They included where the journey started, where the photo was taken, where the car was at the time (the specific location where the journey info feature was asked to be used), where the journey was expected to end (before event suggestion). The figure provided in this table demonstrates all the content in journey info.</td></tr>
<tr><th colspan="2">Book</th></tr>
<tr><td rowspan="2">
</td>
<td>Scope of the simulation based on functionality:
Selection and activation of the book
Browsing the library of books / magazines and selecting one
Browsing the chapters of the book by pointing at the book title
Scrolling and advancing the pages
Closing the book menu</td></tr>
<tr><td>Scope of the simulation based on content:
There was only one reading material which was presented as soon as the book menu was activated. It included only 10 pages; which were enough to simulate the interaction tasks of scrolling and advancing.</td></tr>
<tr><th colspan="2">Event Suggestion</th></tr>
<tr><td rowspan="2">
</td>
<td>Scope of the simulation based on functionality:
Appearance of the notification on head-up display
Reading comments about the suggested event / venue
Accepting the event suggestion
Closing the notification</td></tr>
<tr><td>Scope of the simulation based on content:
The figure provided in this table demonstrates all the content in event suggestion.</td></tr>
</table>

Media	
	**Scope of the simulation based on functionality:** • Selection and activation of the media menu • Browsing the media library • Viewing info about artist/album (e.g. bio) • Scrolling the song list • Selecting a song to play • Scrolling the song list to view the song that will be playing at the next destination • Adjusting the volume • Closing the media menu **Scope of the simulation based on content:** The song list included 10 songs to play in simulation (audio content is available for each one); which were enough to simulate the interaction task of scrolling the song list. As can be seen in the figure provided in this table, the information about the media was limited with the album covers, song and artist names. The details like album name, release date and genre were not included to decrease the amount of little text that would be hard to read with HMD.
'Approaching' Notification	
	**Scope of the simulation based on functionality:** • Appearance of the notification on head-up display • Closing the notification after viewing the information **Scope of the simulation based on content:** The figure provided in this table demonstrates all the content in 'approaching' notification.
Arrival Notification	
	**Scope of the simulation based on functionality:** • Appearance of the notification on head-up display • Viewing the information (picture of brunch menu, a greeting message, time of the event, **attendees**) • Closing the notification after viewing the information **Scope of the simulation based on content:** The figure provided in this table demonstrates all the content in arrival notification. The scope of the content was defined according to the selected event and location.
Deactivation	
	**Scope of the simulation based on functionality:** • Pressing the button on the armrest to deactivate • Being greeted with an animation **Scope of the simulation based on content:** The figure provided (a screenshot from the animation video) in this table demonstrates all the content in deactivation. The animation did not involve any audio content neither in the design nor in the simulation of the design.

Scope of the prototype based on aesthetics of interaction of the front-seat passenger system:

List of all relevant aspects of aesthetics of interaction in front-seat passenger infotainment system are provided in Table 4.14. The aspects that are not included in the scope of prototype or cannot be prototyped in required fidelity due to the limitations of the medium are written *italic* and in '*grey*'.

Table 4.14 Scope of the prototype based on aesthetics of interaction of the front-seat passenger system

Sensory-specific aspects
Visual aspects
• All visual aspects of graphical user interface within the scope of the functionalities and the content • Limited visual aspects of physical controls (touch-sensitive button) and displays (No material effect): e.g. colour, configuration, form (3D), geometry, graphic, layout, pattern, position, proportion, shape (2D), size, transparency, *reflectivity, illumination*
Audio aspects
• All audio aspects of the content in media menu (songs) (e.g. loudness, frequency, timbre) • Limited audio aspects of the physical button click
Kinesthetic aspects
• All kinesthetic aspects of gestures: movement, position • Limited kinesthetic aspects of physical button interactions: e.g. movement, position, *plasticity, rigidity, required force to click* the physical button
Tactile aspects
• Limited tactile aspects of the physical button: e.g. *friction, hardness, temperature, texture*
Gustatory and Olfactory aspects
Not relevant to front-seat passenger infotainment system design
Spatio-temporal aspects
All spatio-temporal aspects within the scope of the functionalities and the content: • Spatial distribution: e.g. lay-out the interface elements within GUI and car interior • Movement range: e.g. movement range of hand gestures • Movement (modest vs. dynamic): e.g. fade-in animations in provision of key information in event suggestion and approaching notifications • Reach: e.g. ready-at-hand physical control on armrest • Orientation, position e.g. direction of the animated arrival notification based on where the arrival point is, orientation of the hand/pointing finger based on the position of GUI elements, orientation of the head while reading a book on HUD • Continuity (continuous vs. discrete): e.g. Advancing pages with a slider • Concurrency e.g. receiving an 'approaching' notification on HUD while interacting with the media menu on TOLED • Timing e.g. timing of HUD notifications • Duration, speed e.g. duration of pointing gesture, fade-in transitions among menus, *time spent in menus (book)*
Action-reaction aspects
All action-reaction aspects within the scope of the functionalities and the content: • Response time: e.g. how instantly the menu appears after its activation on the home menu • Directness (mediated vs. direct): e.g. taking photo directly through head-up display instead of using another viewer in camera menu • Freedom of interaction: e.g. volume adjustment with gestures or touch-sensitive button • Dependency (automatic vs. dependent): automatic head-up display notifications (e.g. event suggestion, arrival, 'approaching') • Sequence (singular vs. plural input): Pointing gesture as a singular input
Presentation aspects
All presentation aspects within the scope of the functionalities and the content: • Proximity (approximate vs. precise): e.g. communication of remaining time to next destination with number of songs in media • Resolution (the richness in information): e.g. inclusion of the pictures of the POIs in the background in journey info • Orderliness: e.g. the linear presentation of the POIs in journey info

Scope of the context:

The decisions on what to be prototyped with regards to the context of front-seat passenger infotainment system interactions were also based on the aim and scope of the research, duration of the simulation and the user study, and limitations of the simulation hardware-software. Following sections explain the scope of the demonstration of the surroundings of the car, the car interior and the car occupants with reference to these concerns.

- **Surroundings of the car:** All functionalities and interactions are to be simulated within a travel scenario and the route points out a 2.5-hours-journey with several points of interests. Therefore, the challenge for the experience prototyping was to create a sense of travelling from A to B and then B to C within the limited duration of the simulation (10-15 minutes). This challenge was handled by making use of still panorama images of selected locations to be changed by the researcher consecutively during the VR demonstration. In the VR simulation these images were applied as textures onto the circular plane surrounding the 3D car model. Therefore, we can claim that the scope of the prototype regarding the surroundings of the car was limited with the medium. Using dynamic content (e.g. dynamic 3D environment, panoramic video footage of 10-15 minutes car travel) was not preferred for not challenging the simulation software by loading bigger data. However, this decision created a limitation for the research, as it was not possible to explore the effects of moving environment on the user experience.

  Surroundings of the car have been referred as a visual and spatial context so far. Nevertheless, other sensory stimuli that result from the road conditions (e.g. shakiness of the car on a bumpy road, traffic noise) were not included in the prototyping. The main reasons were the limitations of the available hardware to communicate some of these aspects and the scope of the PhD research that puts more emphasis on the sensory aspects of the front-seat passenger infotainment system itself rather than the road conditions. However, using their 'imagination', the participants referred to the contextual aspects that were not included in the scope of the simulation, while commenting on the experience of front-seat passenger system. Such comments were taken into account in the analysis of the user study.

- **Car interior:** Demonstration of the front-seat passenger infotainment system within the car interior was significant to make sense of spatial and kinesthetic aspects of the interaction in relation to the car. To exemplify, the inclusion of the car interior enabled exploring if the pointing gestures worked, whilst the user was resting his/her arm on the armrest. In other words, the aim was not only the communication of gestures, but the communication of gestures within the 3D space defined by the car interior. The virtual car interior involved i) the front cockpit (including the windscreen, the steering wheel, driver and passenger dashboard with all displays and physical buttons, central console, side doors-windows and the front seats), and ii) rear seats. The driver cockpit was also involved in prototyping so that the participants could position themselves as the front-seat passengers and feel more immersed in the car interior.

- **Users (car occupants):** The front-seat passenger infotainment system was designed as part of Bentley Continental GT. That is a coupe-type car, which ideally appeals to two users: the driver and the front-seat passenger. Therefore, the travel scenario did not include any other passengers apart from the front-seat passenger. When it comes to the virtual representation of the users, VR simulation presented 'first-person' experience in which the presence of the front-seat passenger was visible in virtual environment only through the virtual hands. The driver did not have a 2D/3D visual representation in VR. However, as the controller of the car, his/her presence was frequently referred as the second occupant sharing the travel experience during the session. This can be explained with the VR concept of 'imagination' (Burdea & Coiffet, 1994).

c. Medium

Based on the collaboration with Virtual Engineering Centre, one of the research objectives was to investigate simulation as a means of experience prototyping. Nonetheless, the decisions regarding i) whether the prototype was going to be an augmented or virtual reality simulation, and ii) the type of the audio/visual/haptic displays and the tracking system to be used in the simulation were finalized after discussion of the design proposals.

The prototype was decided to be a VR simulation considering the following points:

- **Limitations regarding the venue of the user study:** AR prototype would require a continuous access to the real Bentley GT car or its physical car model during simulation development and user studies. Using a virtual car model enabled having these processes within the VEC without any necessity of using a physical prop.

- **Communication of a travel with number of POIs:** Use of VR enabled the use of virtual surroundings and inclusion of any location as part of the travel scenario, therefore, each functionality (infotainment feature) could be experienced in a relevant spatial context in an immersive way.

- **Less need of a tangible item in simulation environment**: Gestures were the main means of control in the front-seat passenger infotainment system. Having touch-free controls for most of the interaction steps eliminated the need of using physical props to be augmented.

- **Experience and expertise of the VEC staff:** The VEC staff had more experience and expertise in development of VR simulations and using VR equipment.

Table 4.15 presents the list of media used in prototyping the front-seat passenger infotainment system and the aspects of interactions and the context that each medium communicates/tracks/modifies.

Table 4.15 Media used in prototyping the front-seat passenger infotainment system

HTC VIVE VR System: VIVE headset (head-mounted display) and SteamVR tracking	
 	It is used for all visual aspects and visual demonstration of spatio-temporal, action-reaction and presentation aspects of the infotainment system. The context of the interaction (the surroundings of the car, the car interior and the car occupants) is also communicated visually in virtual environment. The use of a head-mounted display instead of a power wall can be justified with prototyping spatio-temporal aspects of the interaction as well as the spatial context (surroundings, the car interior) in a more immersive way. The Visualisation section will explain what digital media (e.g. 3D model, 2D images, videos) are used to communicate these aspects in detail. VIVE headset has built-in sensors to track its own position by processing the IR beams that are emitted from two base stations, therefore all spatio-temporal aspects of head movements are tracked and visually communicated by the headset.

Wireless VIVE controller	
	VIVE controller has a circular touch sensitive button. It is used to simulate the aesthetics of interaction of the touch sensitive button on the armrest while the participants are performing the interaction tasks of activation/deactivation by pressing the button and volume adjustment through touch gestures. The controller also has built-in sensors to track its own position by processing the IR beams that are emitted from two base station.
LeapMotion (Hand Tracking System)	
	LeapMotion, the hand tracker which is attached to VIVE headset, is used to track every spatio-temporal aspect of gestural interaction (e.g. orientation of the hand/pointing finger based on the position of GUI elements). These aspects are then visually communicated with the LeapMotion's 3D hand model in virtual environment.
Built-in speakers in TV display	
	The infotainment system design does not involve audio controls or feedback because of the risk of driver distraction. The only audio content that should be involved in prototype is the songs in media menu. Since the aim is to investigate the interactions with media menu rather than how these songs sound; there was no need of using a spatial and hi-fi audio system for the prototype. Therefore, the medium for communication of the audio is the built-in speakers of the TV connected to the VR system.
Other equipment	
	An office chair is used as low-fidelity alternative of a seating buck. Its position and height are adjusted according to the 1:1 scale virtual front passenger seat. A Styrofoam cradle for VIVE controller is positioned according to the virtual touch sensitive button on the armrest. Both props are used to communicate spatial aspects (e.g. reach, orientation)

Prototyping the functionalities means performance of the related interaction tasks and presentation of the related content, which is possible with prototyping the aesthetics of interaction as well as the context where these functionalities are delivered. Therefore, the decisions regarding the medium of the prototype were justified only with reference to these "how dimensions".

d. Fidelity

In this section the fidelity of the prototype is discussed in relation to the functionalities and the content; the aspects of aesthetics of interaction; and the context.

Fidelity of the prototype regarding the functionalities and the content: For functionalities and the content, the scope of the prototype defines *what is prototyped* regarding the *what* of interactions. Since fidelity is defined as "closeness to the real design", it can be claimed that the fidelity of the prototype is *limited with the scope* of the functionalities and the content.

Fidelity of the prototype regarding the aesthetics of interaction:

Visual aspects: Regarding visual aspects, the fidelity of the prototype is limited with the medium. As mentioned earlier, since it is not possible for our eyes to adjust the depth of field in what we see in head-mounted display (since the depth is not physical but virtual); the GUI cannot be provided as sharp as it should be in real car. This applies to all spatio-temporal, presentation and action-reaction aspects that are communicated visually.

Audio aspects: The speakers were able to communicate the audio aspects (loudness, frequency, timbre) listed in Table 4.14, although it was not communicated in a way that users can understand the source of the sound. No digital content was used for the button click for activation and deactivation, it is only communicated with the physical click sound of the button in a low fidelity way.

Tactile and kinesthetic aspects: The VR controller (VIVE) could not communicate any of the tactile (friction, hardness, temperature, texture) and kinesthetic (plasticity, rigidity, required force to click) aspects resulting from the mechanism and material qualities of the actual button, however the functionality (activation-deactivation, volume adjustment) was able to be delivered with different aesthetics of interaction.

Kinesthetic aspects of gestures (e.g. user's movements, physical effort) were experienced through communication of the affordances and feedbacks that guided users while performing gestures. Therefore, the fidelity of the prototype regarding kinesthetic aspects depended on the fidelity of communication of related visual, spatio-temporal and action-reaction aspects of the interactions.

Spatio-temporal aspects: Everything in virtual environment was simulated in life-size 1:1 scale. This way, the simulation provided high fidelity communication of the distances (e.g. spatial distribution of interface elements, reach). But, when there was a movement in interaction, the fidelity of prototype in terms of spatio-temporal aspects was limited with the frame rate of the simulation and the precision of both LeapMotion and VIVE tracking systems.

Presentation and action-reaction aspects of the infotainment system were based on the decisions regarding sensory specific and spatio-temporal aspects. For example, if we refer to the action-reaction aspect of 'directness' (e.g. taking photo directly through head-up display instead of using another viewer in camera menu), the fidelity of the prototype in terms of communication of this aspect depended on how visual and spatio-temporal aspects of the head-up display and gestural controls were communicated.

Fidelity of the prototype regarding the representation of the users and contextual elements

Surroundings of the car: The panorama images for the surroundings of the car had to be provided in low resolution because the size of the circular plane that they are applied as texture had to be bigger than the size of the panorama images.

Car interior: The function of the car interior was to provide a spatial context for the demonstration of the front-seat passenger infotainment system. The simulation did not include a photorealistic rendering of the car interior. The presentation of the material qualities by using textures only applies to the wooden veneer of the passenger dashboard. This way we were able to communicate the aesthetics of visual interactions provided by the transparent OLED display of the infotainment system.

Users: Regarding the presentation of the users, we can only talk about the fidelity of the hands of the front-seat passenger. As can be seen in travel scenario figures, the virtual hands were not as low fidelity as skeletal presentations, but they are not photo-realistic either. This level of fidelity can create a sense of presence especially when performing gestural controls. The 3D virtual hand models that were used in simulation was provided in LeapMotion - HandsModule Unity package.

4.4.2.2 The simulation development process

Simulation development consisted of two main tasks: i) Visualisation, and ii) Programming. Virtual Engineering Centre, as the research partner, actively involved in the simulation development process. Table 4.16 demonstrates the breakdown of the two main tasks with sub-tasks accompanied by the information on the responsible research partner and the time spent for each task.

In the simulation development process, the VEC was responsible for the receipt, conversion and programming of all Bentley 3D data. PhD researcher designed the GUI interactions and supplied all visual materials of the GUI design as UI canvases in Unity. The UI canvases were merged to VR scene and all interactions in the virtual environment were programmed by the VEC. Throughout the process (26 June - 24 November 2017) the author (PhD researcher) conducted 13 visits to the VEC to set the parameters for the aesthetics of interactions with the software engineer, who was working on the programming. During these programming sessions spanning the whole working day, the trials and exchange of feedback between the author and the software engineer enabled instant revisions in the script and the interaction aesthetics. The revisions required for design visualisation were made by the author after each visit, to be transferred to VR scene in the following week's visit to the VEC. In other words, the visualisation and programming were conducted simultaneously, and they were iterative processes feeding each other.

Table 4.16 The main tasks of simulation development

VISUALISATION
Graphical User Interface (GUI) • **GUI design, preparation and collection of the visual (and audio) content, creation of final GUI canvases in Adobe Photoshop and in Unity (VR):** PhD researcher, 14 weeks
Car Interior • **Design and 3D modelling of the touch-sensitive button** PhD researcher, 2 days • **Transformation of the 3D Bentley Continental GT data and the 3D touch-sensitive button data to mesh to be exported to a VR native file type, creation of surface textures and application of the textures to VR scene data:** Visualisation team at VEC (Hung-Ming Chou, Iain Cant), 10 days
Surroundings of the Car • **Collection of Google Street View panorama images based on the travel route defined.** PhD researcher, 2 days (as part of 14-weeks visualisation process of GUI) • **Application of panorama images to VR scene** Software engineer at VEC (Carlo Pinto)
PROGRAMMING
• **Programming all front-seat passenger infotainment system interactions, setting the parameters for spatio-temporal aspects of the interactions (e.g. animations)** Software engineer at VEC (Carlo Pinto), 18 days

a. Visualisation

This section will present the visualisation processes of i) the GUI, ii) the car interior (with controls and displays of front-seat passenger infotainment system), and iii) the surroundings of the car with the source and format information of the any visual media used as part of the design and simulation.

i) Graphical User Interface (GUI)

GUI of the front-seat passenger infotainment system is designed and visualised in a way that it communicates the corporate identity of Bentley Motors. Therefore, Bentley Motors was asked to provide us with the image data (.PSD files) of the most up-to-date (2017) HMI design together with the font type. Figure 4.64 includes two example screenshots from the Bentley Bentayga HMI / infotainment system, and the examples from other software applications of Bentley Motor, such as ‘My Bentley’ and ‘Smart Remote’.

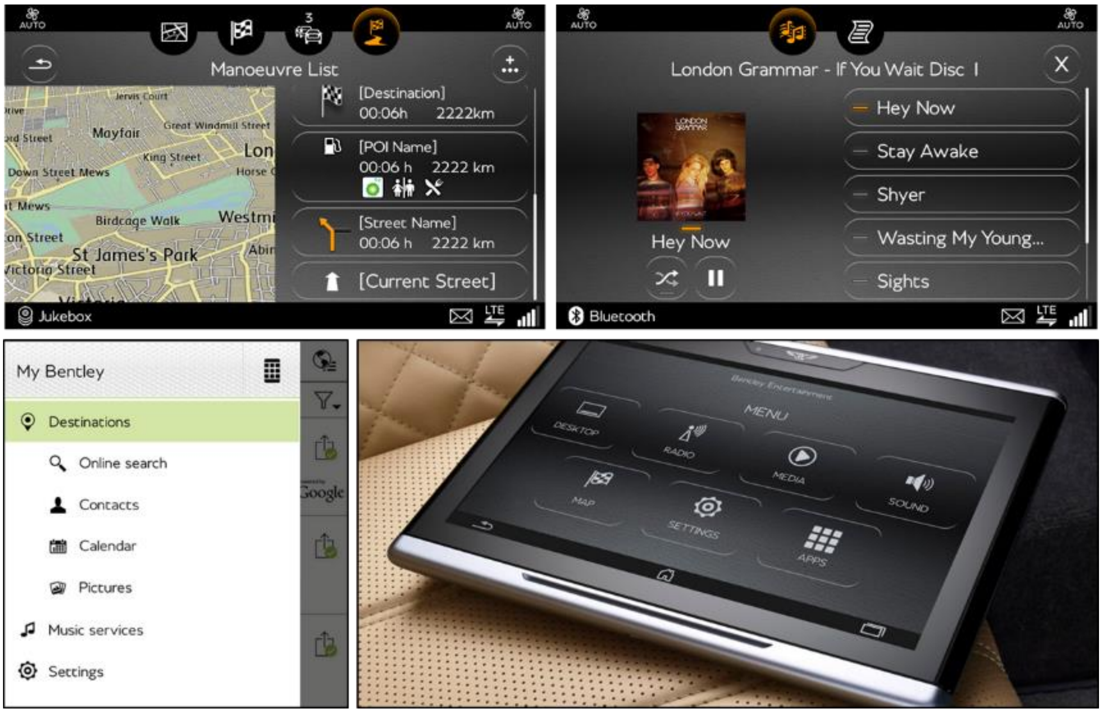


Figure 4.64 Menu screenshots from Bentley Bentayga HMI (Navigation and Media), My Bentley and Smart Remote apps (Apple Inc., 2018; Bentley Motors, 2018)

The colour scheme, the font, the button design and the menu icons of the front-seat passenger infotainment system design were based on the corporate image data provided by Bentley Motors. However, the layout design of all infotainment menus, menu icons for the new infotainment features/functions and all other decisions regarding the visual content (e.g. size of the interface items; selection of photos, map style) were proposed by the author.

The GUI visualisation phases can be listed as:

1. Low-fidelity presentation of the initial travel scenario
2. Preparation and collection of the visual content
3. Creation of final GUI canvases
4. Creation of final GUI canvases in Unity-VR

The simulation of each infotainment menu/feature was developed individually. Accordingly, the visualisation phases of 2-3-4 were repeated for each infotainment menu. Description of each phases now follows:

1. Low-fidelity presentation of the initial travel scenario

The GUI visualisation process started with the low-fidelity presentation of the initial travel scenario. The aim was to demonstrate new functionalities and related content with a draft design. The sketches were produced by the author, using Autodesk Sketchbook Pro app on iPad (Figure 4.65).

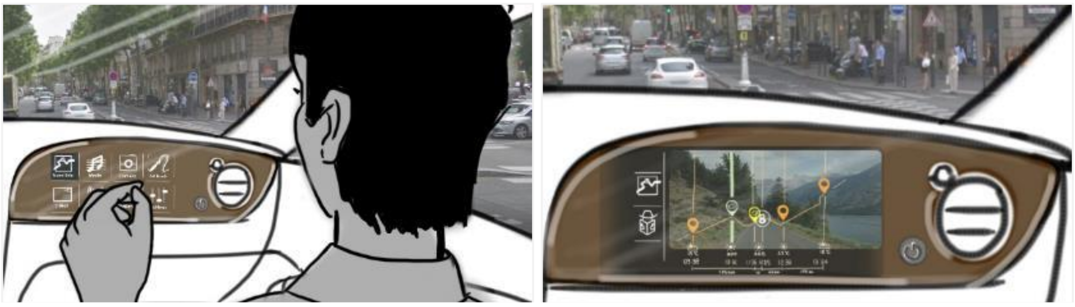


Figure 4.65 Low-fidelity presentation of the initial travel scenario

2. Preparation and collection of the visual content

This phase of visualisation started after defining the scope of the functionalities and the content to be prototyped. It included sketching of the menu lay-outs, re-visualisation of menu icons and other interface elements in Adobe Illustrator according to the lay-out and resolution of the final GUI design. The process also included the selection and collection of other visual content (e.g. venue photos, informative texts, maps) through internet. Table 4.17 demonstrates the sources and formats of the visual content for each infotainment menu.

3. Creation of Final GUI canvases

Final GUI canvases for each infotainment feature were created in Adobe Photoshop (see Figure 4.66 for an example screenshot). This phase of visualisation was carried out in parallel with the programming of VR simulation in Unity, which was an iterative process including revisions in design.

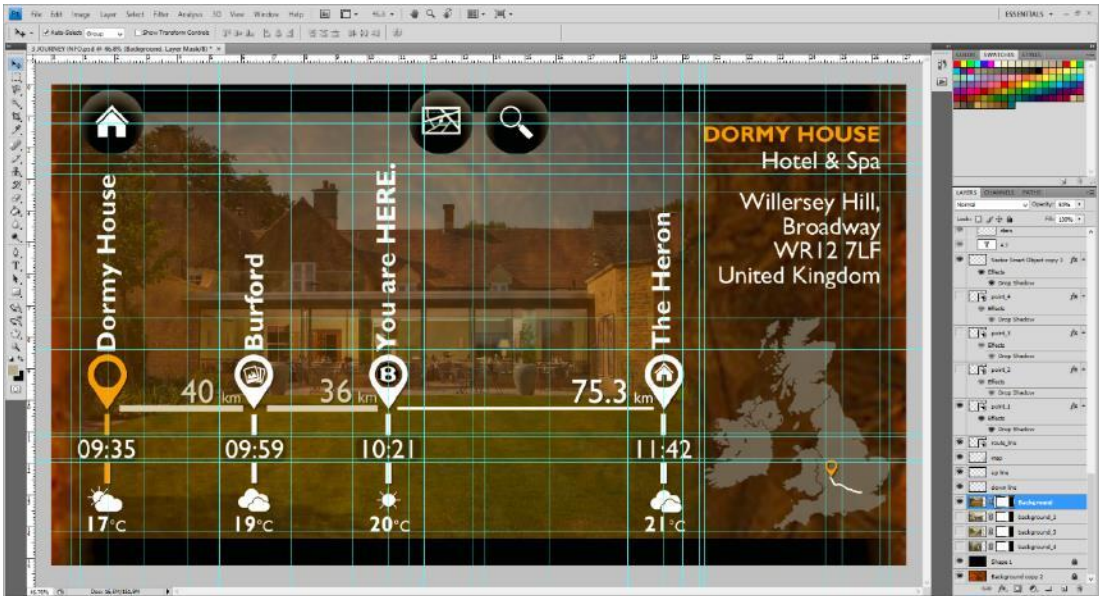


Figure 4.66 Journey info menu canvas in Adobe Photoshop

One of the revisions was changing the latest Bentley Motors corporate font type (BY736) with the previous corporate font Gill Sans (with thicker strokes) and using a bigger font size to make the text more readable in VR (Figure 4.67).

Figure 4.67 Previous (left) and final (right) versions of journey info menu

The layout and size of the interface elements were also revised to make them easier to select with pointing gestures. For example, in Media menu, the number of the songs within the scroll view was decreased from 5 to 4 to have larger buttons for each song. The slider for the volume adjustment was made slightly larger to increase the hit-area. The song list was moved from the middle to the right to avoid accidental interactions with the scroll bar (Figure 4.68).

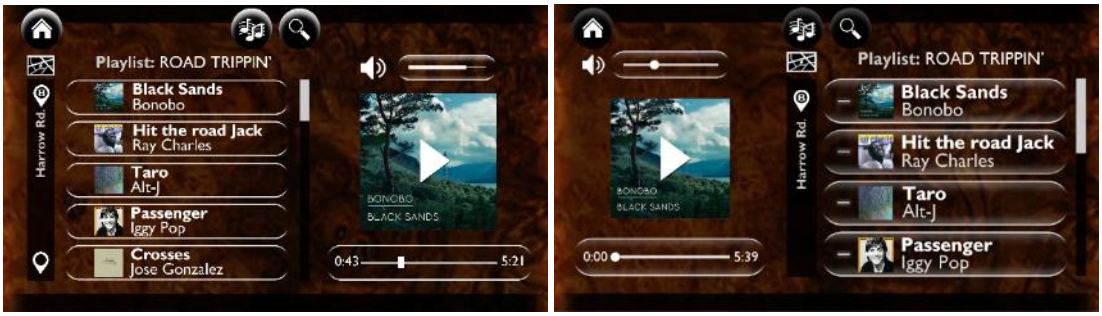


Figure 4.68 Previous (left) and final (right) versions of media menu

4. Final GUI canvases in Unity-VR

Each layer in GUI canvases in Adobe Photoshop was saved as a separate .PNG file format to be exported to Unity as a new user interface (UI) image and laid out based on the designed composition (See Figure 4.69). All animations (e.g. selection and activation feedback in the form of colour change, fade-in animations of notifications) were created in Unity. Only the animation with the Bentley Motors logo was imported as a video file. Finally, the UI canvases were aligned to the relevant surfaces of the 3D VR scene data of the car.

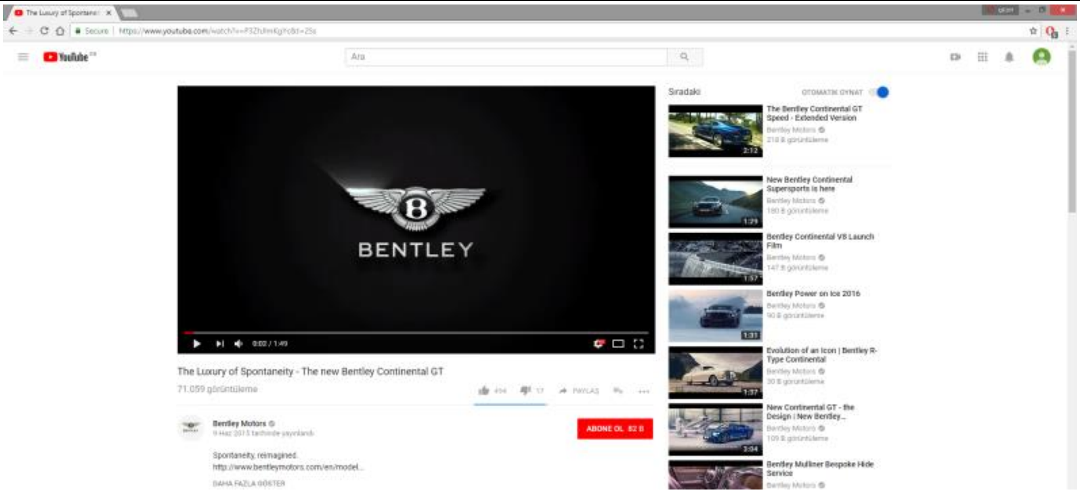
Figure 4.69 Creation of UI canvases in Unity

Table 4.17 explains sources of the visual materials that were utilized in each infotainment menu and how they are formatted based on the GUI design for simulation.

Table 4.17 Source and format of the visual content utilized in infotainment menus visualisation

Activation-Deactivation

The animation was taken from the opening theme of the YouTube video 'The Luxury of Spontaneity-The New Bentley Continental GT' (Bentley Motors, 2015).

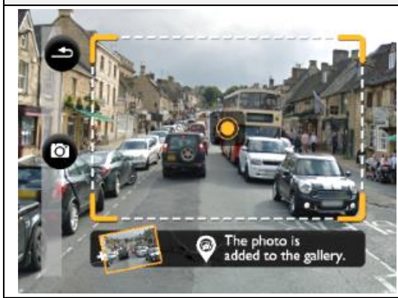


(Bentley Motors, 2015)

Main-Home Menu

The menu icons for all infotainment features (except Book) were based on the icons used in Bentley Bentayga HMI (for Journey Info (Navigation and Media); My Bentley app (Camera, Gallery), and Smart Remote app (Radio, Settings). Please refer Figure 4.64 to view the sources.

Camera



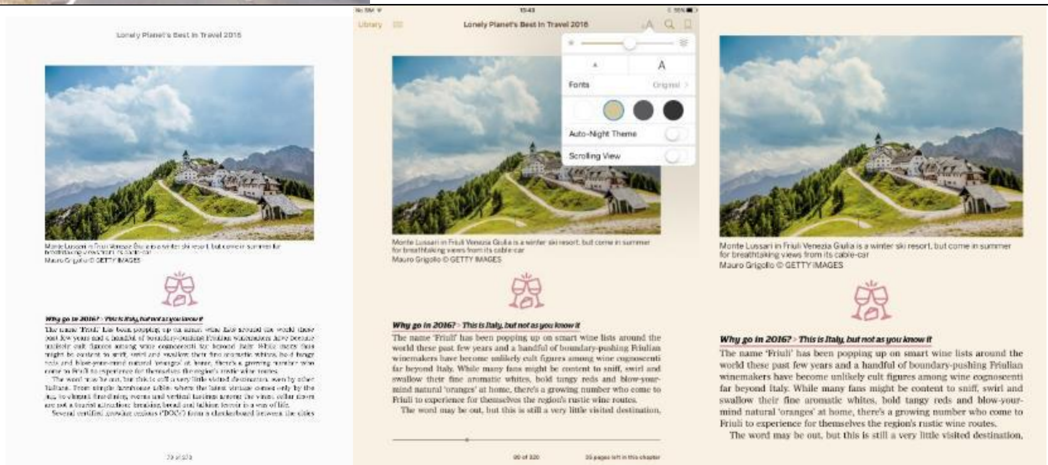
The information provided in feedback of taking the shot was limited with one location and its picture which was cropped from the Google Street View panorama in Figure 4.71.

Journey Info

The sources for the background images for the initial location and the last destination were the websites of Dormy House-Luxury Spa Hotel (2017) and The Heron (n.d). The background images for the current location of the car and the location where the photo is taken were cropped from Google Street View Panorama.

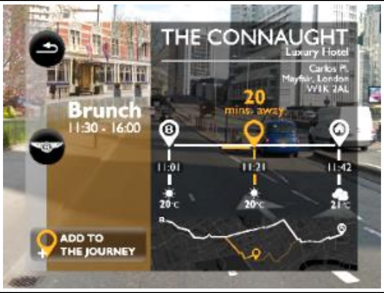
Book

The pages of the book were taken from the iPad version of “Lonely Planet’s Best in Travel 2016” (Lonely Planet, 2016). Before saving screenshots of the selected 10 pages, their format was customised by selecting a background colour, increasing the font size to make the text more readable in VR simulation. Then the screenshots were collected, cropped and added to the ‘viewport’ of the ‘scroll view’ in Unity as new UI images.

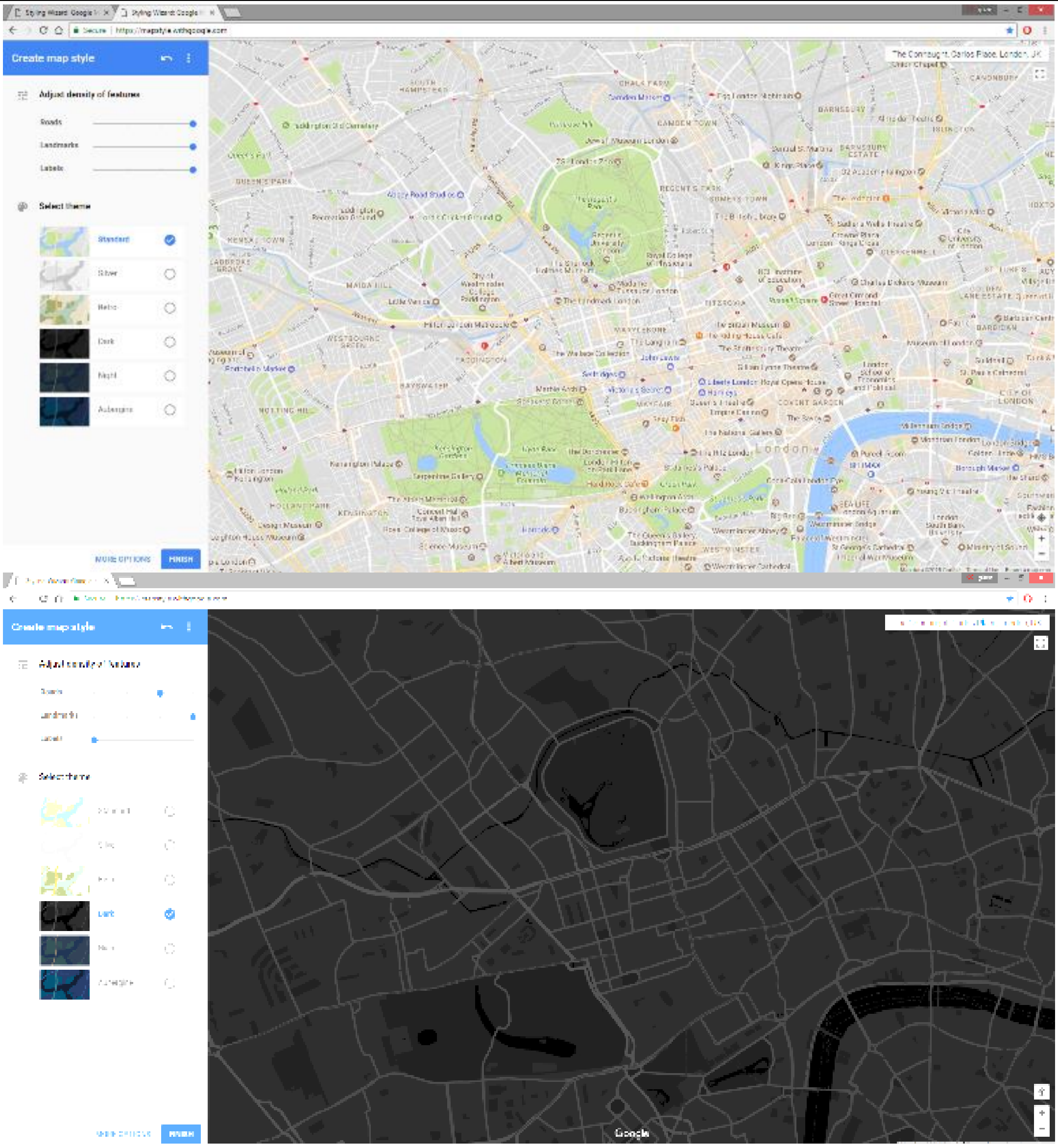


(Lonely Planet, 2016)

Event Suggestion-Approaching Notification



The map provided in both 'event suggestion' and 'approaching' notifications was rendered with 'Google Maps APIs Styling Wizard' according to the colour scheme. The labels in the map were removed not to include any text that would be very challenging to read (in VR).



(Google Maps APIs Styling Wizard, 2017)

Media

All album covers were collected with Google Image Search.

Arrival Notification	
	The logos for The Connaught Hotel, ‘Helene Darroze at the Connaught’ restaurant and the representative image for the brunch menu were collected from the hotel website (The Connaught, n.d.).

iii) Car Interior

Bentley Continental GT 3D car model was provided by Bentley Motors. The parts that were included in 3D data were the dashboard, front doors, seats and the windscreen. The addition to this model regarding the front-seat passenger infotainment system was the touch sensitive button on the armrest. It was modelled in Rhinoceros 5.0 and exported as a .FBX file format to be replaced with the original armrest without the button in the car (Figure 4.70).

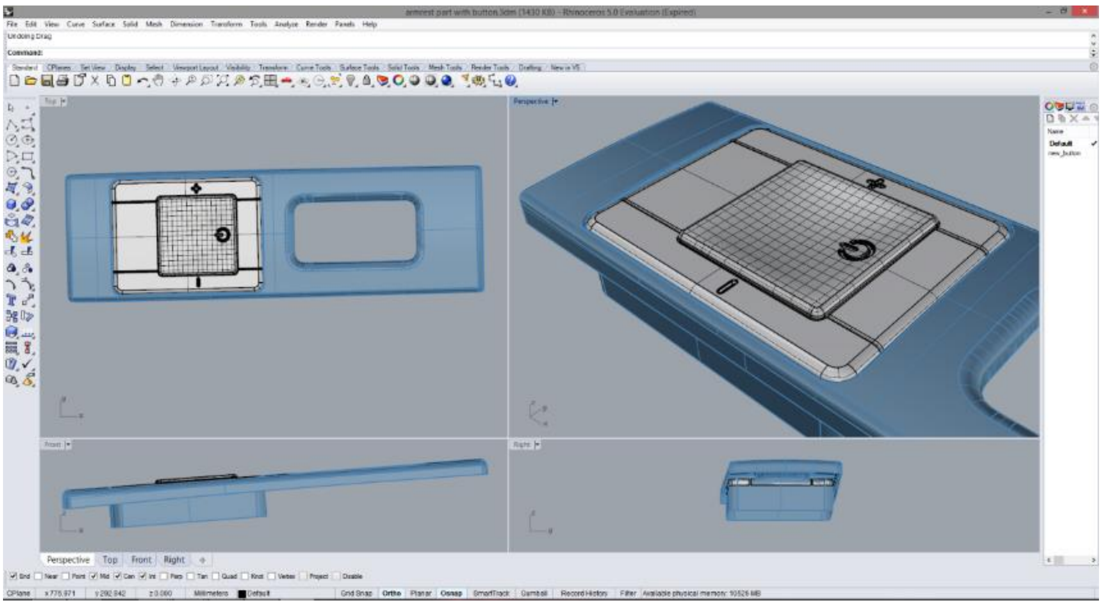


Figure 4.70 3D model of the touch sensitive button created in Rhinoceros 5.0

The visualisation team at the VEC utilized Cinema 4D R18 as the 3D modelling software to transform the 3D data to mesh to be exported to a VR native file type. Then the surface textures were created/edited in Adobe Photoshop and applied to the VR scene data.

GUI design and development had already been initiated when the 3D data was provided by Bentley Motors. Therefore, one of the limitations of the study to have a left-handed car although the visual content in the prototype is based on a travel scenario that takes place in

UK where right-handed cars are used. However, since the interaction tasks did not include anything directly related with the driving activity, using a left-handed car model did not cause a problem in the user study.

iii) Surroundings of the Car

The outside environment was communicated in simulation with still panorama images that were applied as a texture onto a circular surface surrounding the car. The simulation was coded in a way that these panorama images could be altered by the investigator/PhD researcher with the keyboard connected to the VR system (Pressing #1 for Panorama 1). The timing and order of these changes were based on the list of functionalities that are introduced to the research participant.

The surrounding images were collected from Google Street View panoramas, by searching the addresses of the locations on the selected route and virtually travelling to find the best spot to introduce a specific infotainment feature (e.g. finding a picturesque view on High St, Burford to ask participant to take a picture with the camera menu). To save these panorama images, the software and its website 'Street View Download 360' was utilized. The website assigned a panorama ID for each location if the Google Street View URL is provided. The software was used to download the panoramic image in selected file format and resolution based on the panorama ID generated. Figure 4.71, 4.72 and 4.73 show the process including a screencast snapshot from the final VR simulation where the car interior and the surrounding image are rendered together.

Figure 4.71 Street View (39 High St., Burford, UK) (Google Maps, 2016)

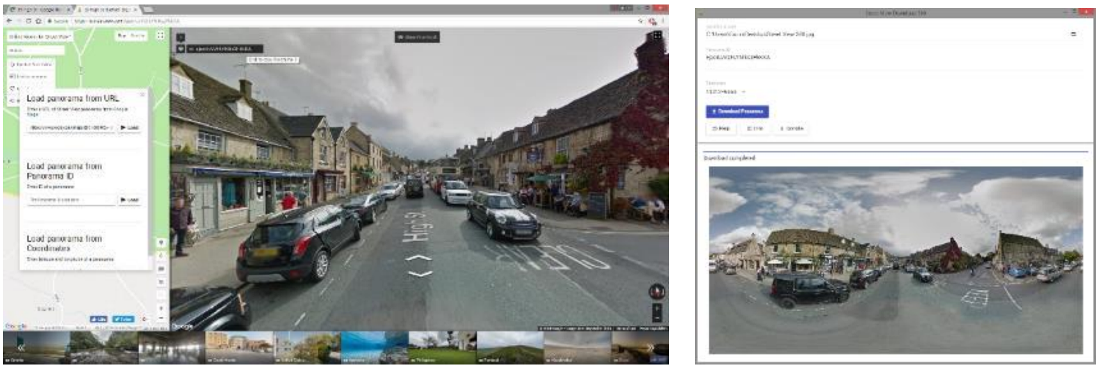


Figure 4.72 Street View Download 360 website and programme

Figure 4.73 VR screencast view with the car interior and the panoramic environment texture

b. Programming

Programming the interactions within virtual environment was mostly related with the participant's interactions with the infotainment system. The scope of the interaction tasks and the aesthetics of interaction included in VR simulation can be viewed in Tables 4.13 and 4.14. It is important to mention that the VEC delivered the virtual hand interactions of the simulation by innovatively adapting their knowledge of a 'ray tracing' tool, which significantly enhanced user interactions.

In addition to the programming required for the participant's navigation and interactions within virtual environment, programming also included coding that enabled the PhD researcher to control the VR system based on the travel scenario and the user study plan. The programming tasks can be exemplified altering panorama images with number buttons (pressing #2 for panorama image 2), pressing the "N" button on the keyboard to activate the "automatic" notifications which were supposed to appear only in specific locations.

The software used in creation of virtual environment and programming the interactions within the virtual environment include the following:

The game engine:

- Unity (version 5.6.3f1)

Tracking-VR platform:

- SteamVR (version 1515522829) – Steam (package version 1513371133)
- Unity Package: SteamVR (version 1.2.2)

Gesture tracking with LeapMotion:

- Leap Developer Kit – Orion (version 3.2.1 – Firmware revision 1.7)
- Unity Packages: LeapMotion Core_Assets (version 4.3.3), LeapMotion Hands Module (version 2.1.2)

CHAPTER 5.

EXPERIENCE PROTOTYPING OF THE FRONT-SEAT PASSENGER INFOTAINMENT SYSTEM THROUGH VR SIMULATION

5.1 Introduction

The main aim of the PhD research was to investigate the relations among the luxury user experience (*why* level), the aesthetics of the infotainment interactions (*how* level), and the infotainment system functionalities & content (*what* level); and to discuss the design directions for the future front-seat passenger infotainment systems with reference to these relations. Therefore, in the experience prototyping study, VR simulation was utilized to provide research participants with an interactive and immersive experience of the front-seat passenger infotainment system proposal. They were then asked to reflect on the varied qualities of experience by referring to the aesthetics of interaction and the functionalities provided by the system. Through the analysis of the participants' reflections to user experience of the VR prototype of the infotainment system, this study identified design directions for future front-seat passenger infotainment systems experience with reference to the *why, what* and *how* dimensions of interacting with technology.

This chapter presents the methodology (the study set-up and details), the analysis and the results of the experience prototyping study that utilized the VR simulation of the front-seat passenger infotainment system. The sections cover 5.2 Study Set-up and Details, 5.3 Analysis Overview, 5.4 Evaluation of the VR Simulation, 5.5 Evaluation of the User Experience of the Front-Seat Passenger Infotainment System and 5.6 Discussion.

Section 5.2 Study Set-up and Details first introduces the venue, participants (sampling/exclusion criteria and recruitment) and the study protocol. This information is followed by the demonstration of all the research materials used in data collection, including simulation setting & equipment; simulation evaluation materials (simulation sickness and presence questionnaire) and user experience evaluation materials (user experience evaluation questionnaire and semi-structured interview) that are utilized before/during/after the VR demonstration of the travel scenario which contains the final front-seat passenger infotainment system proposal.

5.3 Analysis Overview explains the details of the data analysis process.

5.4 Evaluation of the VR Simulation presents the results of the simulation sickness and presence (realism) questionnaires.

5.5 Evaluation of the User Experience of the Front-Seat Passenger Infotainment System discuss the analysis and results of the user experience evaluation through following sections:

Section 5.5.1 demonstrates the results of the UX evaluation questionnaire through which the participants rated the infotainment system based on the semantic differential pairs that identify different qualities of luxury user experience.

Section 5.5.2 presents the underlying reasons of the questionnaire ratings. It investigates which specific aspects of infotainment interactions and functionalities played the biggest role in association of the infotainment experience with either of the semantic differential pairs. The section also includes a list of keywords/phrases referred by the participants during their appraisals, which reveals that there are other ways to describe the expectations from a (luxury) infotainment experience.

Section 5.5.3 presents the infotainment features with the highest and lowest expected frequency of use.

Section 5.5.4 provides an analysis of the participants' suggestions for future front-seat passenger infotainment systems. It presents the ways to improve or enrich: i) the infotainment features & content and ii) aesthetics of interaction of the infotainment system. It also elaborates on the motivations underlying the participants' suggestions for the system, which makes the results more generalizable for other front-seat passenger-oriented infotainment applications.

Section 5.5.5 presents a framework to conceptualize the front-seat passenger's changing roles and relations with the infotainment system. The framework visualizes the relations among the main actors and components of the front-seat passenger infotainment system and shows the different modes when these actors and components are weakly or strongly connected. The same section also presents the ways to facilitate each mode in *how* and *what* level through interactions, functionalities and related content.

The chapter concludes with 5.6 Discussion of the experience prototyping results, with bullet points to consider in 'future front-seat passenger infotainment system designs'.

5.2 Study Set-up and Details

5.2.1 Venue

All sessions were conducted at Virtual Engineering Centre, Sci-Tech Daresbury, UK.

5.2.2 Participants

In total, 27 participants (6 female, 21 male) were recruited in the study.

Sampling, selection (and exclusion) criteria: To take part in the study, the participants were expected:

- to travel as car passengers in daily life,
- to be at least 18 years old,
- not to be over-sensitive to activities that might create motion sickness

The research participants were selected from those who travel as a car passenger in daily life, since the aim was to prototype the interactions with a front-seat passenger infotainment system in VR and to find out how the system can enhance the front-seat passenger's journeys. Additionally, being a driver did not constitute a reason for exclusion.

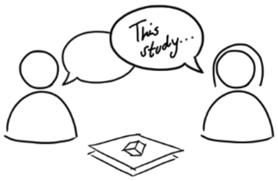
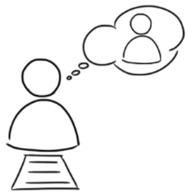
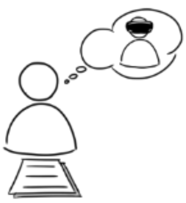
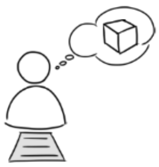
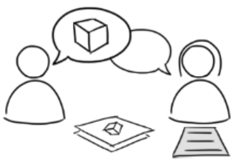
Benefits in taking part in research: There was no immediate benefit for the participants other than offering them a chance to experience VR in an automotive context and to gain insights about the development process of future passenger-oriented automotive user interfaces.

Recruitment process: Participants were recruited with an advertisement poster (Appendix 6) that was published online in social media and distributed within e-mail groups (PGR students in University of Liverpool, the VEC staff) besides through personal communication with the Sci-Tech Daresbury staff working at the VEC, STFC (Science and Technology Facilities Council) and IBM considering their easier access to the venue. The travel expenses of the research participants based in Liverpool were covered by the EPSRC-RSTG fund (1615184) of the PhD project.

5.2.3 Study Protocol

Table 5.1 demonstrates the steps of a study session which took for approximately an hour. The study was led by the PhD researcher. VEC staff supported the set-up and calibration of the equipment used for VR simulation (e.g. HTC VIVE headset, controllers and base stations) and data collection (e.g. webcam).

Table 5.1 Study protocol

Review of participant information sheets and consent forms	***(app. 10 mins)***
	Introduction of the study details to the participant and taking his/her consent for data collection (See Appendices 9 and 10 for participant information sheet and consent form). This part of the session also included a very brief explanation of the key elements of the infotainment system design and the travel scenario.
1. Questionnaire	***(app. 2 mins)***
	Filling in a simulation sickness questionnaire to understand if the participant feels any discomfort before using VR headset.
2. Warm-up Session	***(app. 5 mins)***
	Getting used to the VR equipment (VR headset) and interacting with the system (using hand gestures and the touch sensitive button provided) before the demonstration of the front-seat passenger infotainment system.
3. VR Demonstration of Front-Seat Passenger Infotainment Interactions	***(app. 15 mins)***
	Being introduced several infotainment features (e.g. media) within a travel scenario and asked to perform simple interaction tasks (e.g., scrolling through a list) as a front-seat passenger. The PhD researcher sat next to the participant during the demonstration as a narrator of the travel scenario She explained the next interaction task in each step and was able to monitor what the participant was doing in virtual environment through the TV display connected to the headset (See Figure 5.1 and Appendix 9).
4. Questionnaire	***(app. 2 mins)***
	Filling in i) the simulation sickness questionnaire again to understand if using VR headset caused any discomfort for the participant and ii) presence questionnaire
5. User Experience Evaluation and Follow-up Interview	***(app. 35 mins)***
 	Filling in a small questionnaire to rate the user experience of the infotainment system; discussing the reasons behind the evaluation and sharing opinions and/or suggestions about the system further in an interview. The participants were provided a visual presentation of the interaction steps they went through in VR demonstration. They were able to refer to these presentation boards (Figure 4.76) while reflecting on their experience.

5.2.4 Research Materials

a. Simulation setting & equipment

Section 4.4.2 already introduced the equipment / software utilized in VR simulation. This section shows how they were set and distributed in the venue as well as the specific equipment/software used in data collection (audio-video recording, screencast). Please refer to Figure 5.1 and Table 5.2.

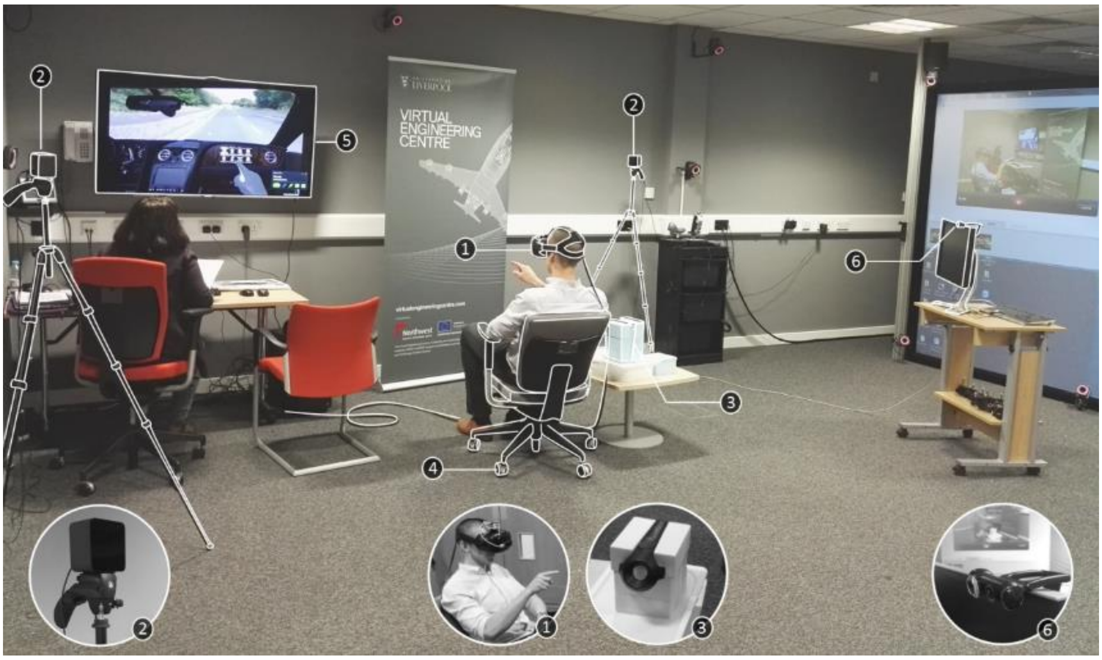


Figure 5.1 Simulation setting & equipment

Table 5.2 Hardware-software used in VR simulation and data collection

VR system	
HTC VIVE Headset	❶
Base stations (Lighthouses) + Manfrotto compact aluminium tripods	❷
VIVE controller + Styrofoam cradle	❸
Hand tracking	
LeapMotion Universal VR Dev Bundle (controller and mount)	❶
Office chair with adjustable seat and armrest height	❹
Live monitoring of the participant's first-person VR experience	
Samsung 55" TV	❺
Sound system	
Samsung 55" TV – built-in speakers	❺
Video recording	
Logitech QuickCam Pro 9000 Webcam, Logitech Webcam Software (version 2.51)	❻
Audio recording	
iPhone SE, Voice Memo application	
Screencasting	
Camtasia Studio - Camtasia Recorder (version 8.4.3)	

b. Simulation evaluation materials

The main aim of this study was to gather data about user experience of the front-seat passenger infotainment system through virtual reality simulation. However, the study involved not only investigation of the design proposal to inform UX research, but also evaluation of the VR simulation itself as a tool. The simulation evaluation was two-fold: measurement of i) simulation sickness and ii) presence.

Simulation Sickness Questionnaire: Section 2.5.6 "Advantages and Disadvantages of using VR in User Studies" introduced the definition of simulation sickness as "a form of induced motion sickness that results from the conflicts between the visual and bodily senses" (Oculus Developers, 2017). The simulation sickness may include symptoms like eyestrain, nausea, dizziness etc. (Kennedy et al., 1993).

The risk of experiencing such a 'conflict between the visual and bodily senses' was low in this study since both the visual environment (use of still images to simulate travelling from A to B) and the research participant (remaining seated during and after simulation) were static. Nevertheless, technology-related (e.g. frame rate, resolution, weight of the VR headset) and participant-related (e.g. age, sensitivity to motion sickness) factors might have caused simulation sickness symptoms, for this reason, the questionnaire was administered before and after the VR demonstration to detect the existence of any potential discomfort or sickness, which might play a role in participants' performances or design evaluations. To measure simulation sickness, the participants were provided with a simulator sickness questionnaire (SSQ) (Kennedy et al.,1993) before and after the VR demonstration (see Appendices 2 and 10).

Presence Questionnaire: The participants were asked to evaluate the simulation in terms of 'presence' that was defined in Section 2.5.4.2 as "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998: p.225). To measure this, the presence questionnaire, introduced by Witmer & Singer, (Vs. 3.0, 1994) and revised by the UQO Cyberpsychology Lab (2004), was administered to the participants (Appendix 11).

The original presence questionnaire consists of the questions that measure a variety of aspects of presence: *realism, possibility to act, quality of interface, possibility to examine, self-evaluation of performance,* and *communication of sounds and haptics*. In this study, the participants were only provided with a selection of *realism*-related questions of the presence questionnaire, since the main aim was to understand if the simulation appeared realistic and natural enough to help the participants envision a real car journey, in which they interact with the infotainment system presented in the simulation.

The questions related with other aspects of presence (e.g. possibility to act, quality of interface, possibility to examine, self-evaluation of performance) were not included in the presence evaluation of this study, since these aspects were going to be discussed as part of UX evaluation. To exemplify, in UX evaluation questionnaire and follow-up interview, the participants rated and commented on the quality of the interface (e.g. how captivating the infotainment system was) and performance related qualities of experience (e.g. how manageable and efficient the infotainment system was). On the other hand, the reason for elimination of the presence aspects that were related with communication of haptics and sound was the fact that the design and simulation mostly relied on other sensory modalities (e.g. use of gesture recognition as the input and elimination of audio feedback from the output)

Appendix 12 shows the presence questionnaire questions provided in the study; which correspond to the 'realism'-related questions (3rd ,7th, 10th and 13th) of the original presence questionnaire (Appendix 11). The question No.10: "How compelling was your sense of moving around inside the virtual environment?" was slightly revised in this study as "How compelling was your sense of navigating around inside the virtual environment?" since the participants were navigating through the virtual infotainment system and the virtual car interior but not "moving" in the virtual environment. They remained seated; the simulated journey included neither the phases of getting in / out of the car nor dynamic surroundings.

c. UX evaluation materials

UX evaluation was twofold in this study and it integrated i) a semantic differential questionnaire (Appendix 13) and ii) a follow-up semi-structured interview (Appendix 14). Use of mixed methodologies or inclusion of the follow-up interview can be justified with the research through design and prototyping approach, where the main aim was not to rate the design based on a set of criteria, but to understand the reasons behind users' ratings regarding the user experience of the infotainment system.

Semantic differential questionnaire: After the VR demonstration, the participants were asked to rate their experience of the front-seat passenger infotainment system on a questionnaire. The questionnaire was a seven-point Likert scale with semantic differentials that correspond to various qualities of user experience (See Table 2.3). This scale was adapted from AttrakDiff Questionnaire (Hassenzahl, 2003; Hassenzahl et al., 2015) based on hedonic-pragmatic qualities of user experience. Some of the sematic differential pairs were eliminated, altered or added to be utilized in the study. The main motivations behind these revisions were:

- to eliminate the number of sematic differentials. The participants were expected to talk about the reasons behind their ratings for each semantic differential pair in the follow up interview; so that we can understand which aspects of interaction or which functionality played role in positive vs. negative appraisals. The number of semantic differential pairs were decreased to avoid repetitions in answers for each luxury value/experience quality and to keep the interview time within 35-40 minutes.

- to include the keywords that are most relevant to Bentley Motors corporate identity and experience,

- to include an individual semantic differential item for the experience of "luxury" in the scale to see what other experience qualities than the ones that the scale covers are referred by the participants to explain their expectations from the infotainment system in a luxury car.

The revisions were made under the supervision of the Bentley Motors HMI design team. They were asked to select/eliminate the keywords presented in AttrakDiff questionnaire or replace them with the corresponding keywords collected from Bentley Motors website and corporate materials (e.g. persona and brand identity documents) provided by the firm. The aim was to have four keywords for each luxury value / experience quality, as it was thought to be a more manageable number.

Figure 5.2 presents the alterations that formed the final questionnaire used in the user study. The selected keywords are written bold. As discussed in detail in Literature Review, Figure 5.2 also shows how these semantic differential keywords relate to the luxury values (Reddy & Terblanche, 2005; Berthon et al., 2009; Kapferer & Bastien, 2009; Wiedmann et al., 2013); product pleasures (Jordan, 2000; Tiger, 1992), and human needs (Sheldon et al., 2001).

In addition to the bold-written semantic differential keywords in Figure 5.2, the final questionnaire involved *"My infotainment experience fails to answer my expectations from* a luxury car - My infotainment experience answers my expectations from a luxury car" statement for the participants to rate and comment on *luxuriousness*.

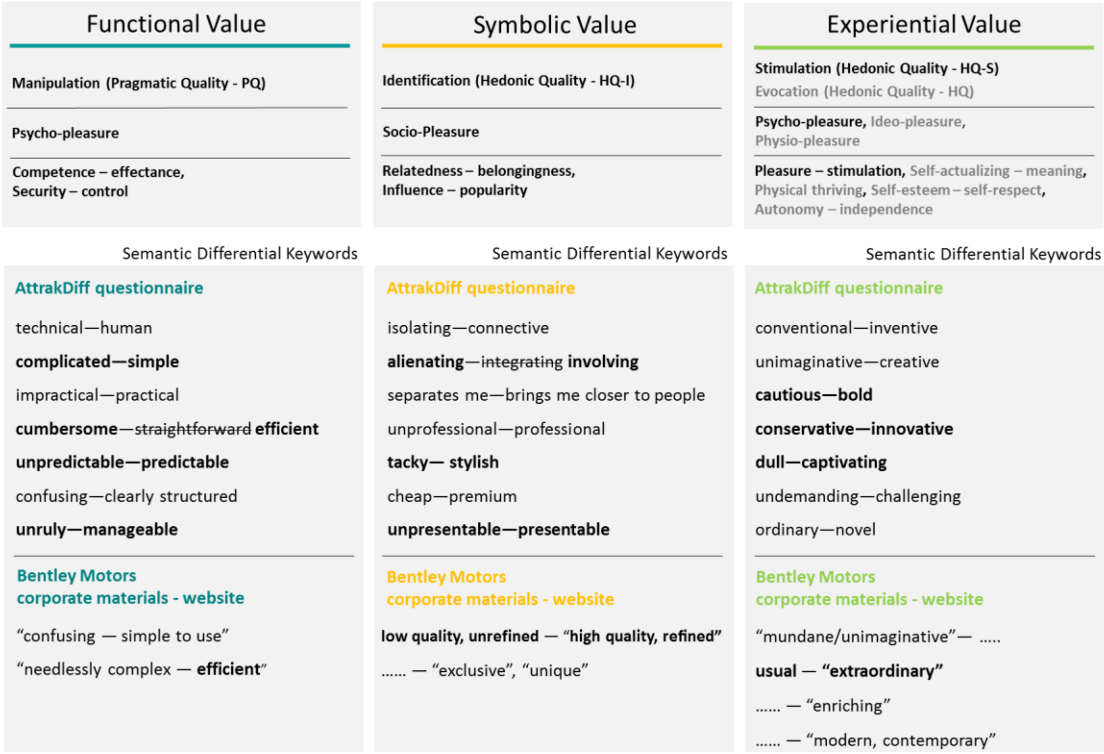


Figure 5.2 Selection of semantic differential keywords (bold) to evaluate user experience

Interview: The last step of the study session was the semi-structured interview. During the interview the participant was provided with four A3-size presentation boards (Figure 4.76) for them to refer to the infotainment system's design and experience. The four boards were: i) controls and displays of the infotainment system (x 1), ii) travel scenario (x 1), and iii) the interaction steps taken to deliver each infotainment task/feature (x 2).

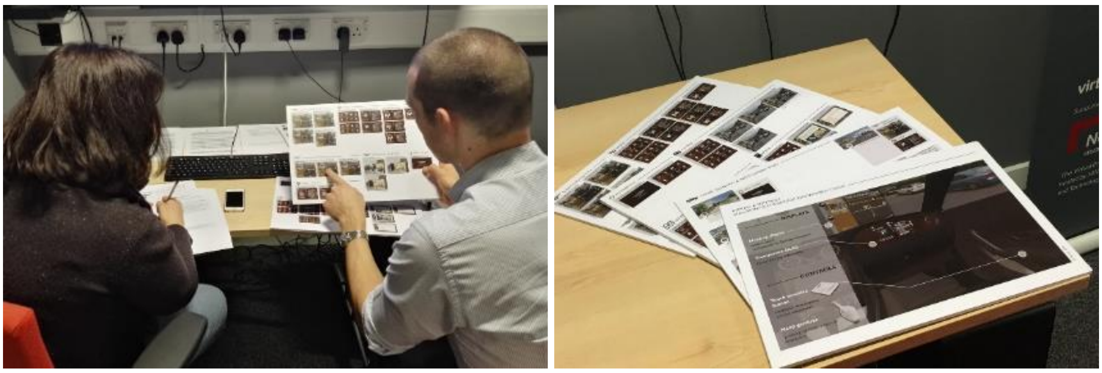


Figure 5.3 The research participant referring to presentation boards during interview

The interview was audio-recorded with iPhone SE-Voice Memo app to be transcribed before data analysis. The importance of each question for the research follows:

- **Question 1: "What made you think that your experience is more [semantic differential-x] than [semantic differential-y]?"** was repeated for each semantic differential item to investigate how a specific quality of user experience / luxury value (e.g. symbolic value-identification: tacky vs. stylish) is associated with a specific aspect of interaction aesthetics (e.g. action-reaction > dependency, automatic head-up display notifications) or a specific functionality (e.g. accessing journey info); in other words, to investigate the links among *why, how* and *what* of the front-seat passenger infotainment system.
- **Question 2: "How was your overall experience? What do you think can be improved, what would you change?"** was asked to wrap up the discussions in Question 1, to see if participants have additional positive or negative comments on their user experience and to investigate the areas of improvement.
- **Question 3: "If you had such system in a car: a. Which infotainment features (from the ones that you are offered) do you see yourself using the most/least? b. What other infotainment features would you like to see? What other activities would you use it for?"** focused more on usefulness rather than usability to identify the most/least favourable infotainment features and investigate the user needs for other functionalities.
- **Question 4: "Thinking of your previous "passengering" experiences, in what ways do you think this system can improve your journeys?"** encouraged participants to compare their infotainment experience with their past experiences of being a front-seat passenger to identify the added values provided by the system and to see what qualities of experience were referred while the participants were talking about these added values.
- **Question 5: Thinking of your previous "passengering" experiences, what can go wrong in this system?** encouraged participants to be more critical about the new functionalities and interactions provided by the infotainment system by referring to a variety of travel contexts they had experienced before but were not covered within the scope of the travel scenario in the simulation.

5.3 Analysis Overview

Both quantitative and qualitative analysis methods were employed in this research: i) quantitative analysis of the simulation sickness (SSQ), presence – realism (PQ) and the user experience evaluation (UXQ) questionnaires and ii) content analysis of the follow-up interviews.

For the quantitative analysis of the data that were collected with the questionnaires, participants' responses on A4 sheets were transferred to spreadsheets and the results were visualized with Microsoft Excel's graph functionality.

For the content analysis, the audio-recordings of the interviews were transcribed in Audiotranskription's 'f4transkript' software. Then, each interview transcript was transferred to the qualitative data analysis software NVivo Pro 11 as 'sources' of the data. The participants' responses were then coded / assigned with a category by highlighting the relevant part of the responses. The main categories that were used in coding were either pre-defined with the terminology from the UX literature or created during the content analysis. The categories that were derived from the literature included the semantic differentials used in the UX evaluation questionnaire (e.g. extraordinary vs. usual) and the aspects of aesthetics of interaction (e.g. spatio-temporal aspects: range of movement). The categories that were created during the content analysis included 'additional qualities of experience', 'concerns and challenges', 'relations among the actors and components of the infotainment experience', and 'suggestions'.

To find the number of participants who referred to two specific categories together, which was needed to investigate the relations among different set of categories, the matrix coding query function of NVivo Pro 11 was used. For example, to see which aspects of interaction (e.g. visual, action-reaction) played role in delivering a specific quality of experience (e.g. extraordinary vs. usual); the rows of the matrix were defined as the list of aspects of interaction and the columns were defined as semantic differential keywords. As a result of the query, NVivo generated a chart with cells that includes the number of sources where one specific quality of experience (e.g. extraordinary) is associated with one specific aspect of interaction (e.g. spatio-temporal > pop-ups) (Figure 5.4). The generated chart was then exported to Microsoft Excel to visualize the quantified relations with graphs. Please see the section 5.5.2 for the results of the analysis.

Figure 5.4 Matrix coding query results after elimination of the rows and columns with zero match

During the interview analysis, the video recordings of the user study session and the screencast records of the participants' first-person VR experience were used as supplementary data. They were utilized when there was a need for a visual reference to understand what participants talked about during the interview session (e.g. pointing to a specific part of the presentation boards or a specific challenge they experienced). The screenshots of the screencast records can be seen in Section 4.4.1.4 where the travel scenario and interactions were described.

5.4 Evaluation of the VR Simulation

Use of VR as part of the user experience evaluation necessitated the evaluation of the VR simulation itself as well. It was to confirm that the participants felt well and present enough so that we could rely on their reflections on the design proposal. As mentioned earlier, simulation evaluation was twofold: i) to understand whether the VR demo causes any symptom of simulation sickness – this was investigated through the administration of the Simulation Sickness Questionnaire before/after the VR demo; and ii) to measure the presence (realism) of the simulation with the Presence Questionnaire. Following sections will present the results of the questionnaires.

5.4.1 Simulation Sickness Questionnaire (SSQ)

As can be found in Appendix 15, the mean scores for all simulation sickness symptoms before and after the VR demo are under 1.00 at the scale ranging from 0 to 3. With the inclusion of standard deviation, only the symptom of fatigue reaches 1.04 (after VR demo); however, it is measured as 0,90 with SD already before the demonstration. The highest differences are observed in eye strain and general discomfort. The increase in the severity of the eye strain can be explained with the low resolution of the surroundings as well as the difficulty in focusing on the text-based content of the GUI in virtual environment. On the other hand, the increase in general discomfort was mostly related with the weight of the HTC-VIVE headset by the participants while filling in the questionnaire. As a result, no major difference was found out between the severity ratings of the simulation sickness symptoms before and after the VR demo.

5.4.2 Presence Questionnaire (PQ)

The results of the presence questionnaire with 7-point Likert scale can be found in Appendix 16. As mentioned earlier, the questions in presence questionnaire were selected to measure realism in terms of i) naturalness of the interactions in VE, ii) sense of involvement in VE, iii) consistency with real world experiences, and iv) sense of navigating around inside VE. The internal evaluation shows that the mean scores calculated from 27 participants' ratings for each question are above 5 in a 7-point scale. Therefore, it can be claimed that the VR simulation were more towards realistic or natural that the participants could figure out how it would be like to interact with front-seat passenger infotainment system in a real car context. As an external baseline; UQO Cyberpsychology Lab (2004) administered the original questionnaire with seven realism-related questions to 101 participants using VE. The results showed total mean score of 29,45 out of the total maximum score of 49, which corresponds to approximately 60 percent of the total maximum score for realism (See Appendix 11). In this PhD study, the total mean score for the four realism-related questions were 21,81 out of the total maximum score of 28; which corresponds to approximately 77 percent of the total maximum mean score.

5.4.3 The Relation among Simulation Sickness, Presence and User Experience Evaluations

The results of the user experience evaluation questionnaire will be discussed in following sections in detail, however, Appendix 17 provides another graph that demonstrates whether there was an observable relation among the simulation sickness, presence and user experience ratings through the total scores (percentages out of the possible max. score) collected from each questionnaire across each of the 27 participants. The results do not show a direct (or inverse) relationship among the scores. Only for the participant 6 (P6) we can draw the conclusion that the (simulation) sickness may have affected the presence in virtual environment.

5.5 Evaluation of the User Experience of the Front-Seat Passenger Infotainment System

This section will first present the results of the user experience evaluation questionnaire, which consists of 13 semantic differential pairs that were utilized as metrics to measure the pragmatic and hedonic qualities of user experience that correspond to luxury values (functional, experiential, symbolic). However, the aim of the experience prototyping was not only to measure the front-seat passenger infotainment system prototype based on these metrics; but also, to investigate what aspects of the system (*how* level: aspects of aesthetics of interaction and *what* level: functionalities and content) played role in delivery of these qualities of user experience / luxury values. Therefore, the questionnaire results will be followed by the analysis of the semi-structured interviews, where the participants were encouraged to elaborate on the reasons behind their ratings, to provide suggestions and share their concerns (if any) about the infotainment system.

5.5.1 User Experience Evaluation with Semantic Differential Questionnaire

Figure 5.5 demonstrates the results of the user experience evaluation with semantic differential questionnaire. As can be seen in Figure 5.5, the mean score for each semantic differential pair in the 7-point user experience evaluation scale is above 5. These results show that, for each semantic differential, the user experience ratings of the front-seat passenger infotainment system prototype are more towards the positive. It is observed that highest scores are given to the semantic differentials that define the functional value/pragmatic quality (simple, efficient, manageable and predictable); whereas the mean scores for hedonic quality-stimulation-related semantic differentials (innovative, extraordinary, bold, captivating) are slightly lower compared to other qualities of experience. The reasons behind the ratings will be discussed in detail in the following section with the content analysis of the follow-up interview.

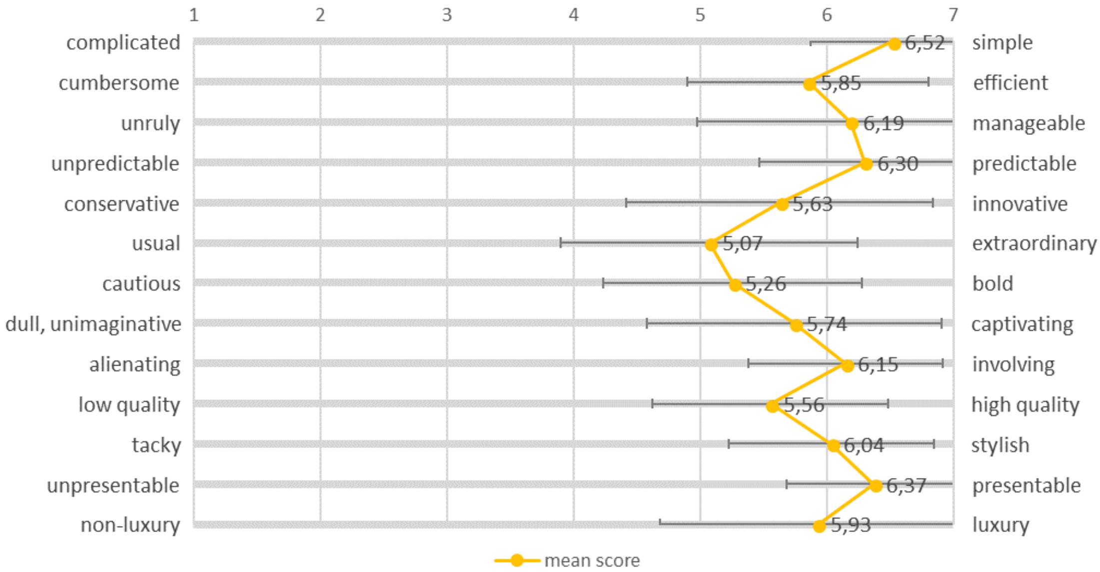


Figure 5.5 Mean scores for user experience evaluation with semantic differential pairs

5.5.2 Qualities of Experience and Front-Seat Passenger Infotainment System

In the user study, the UX evaluation questionnaire was followed by a semi-structured interview. One of the questions in mind while conducting the follow-up interview was: “What front-seat passenger infotainment system aspects play (more) role in delivery of the qualities of pleasant user experience (identified in the UX questionnaire with semantic differential pairs)?” To analyse the responses given to this question the literature reviews on “the dimensions of how: the aspects of (aesthetics of) interaction” and “the dimensions of what” were used as references (see Figure 2.5). This way, it was possible to differentiate the participants’ comments about functionalities from their comments about the aesthetics of interaction. These dimensions also enabled the deconstruction of the participants’ comments about the interaction aesthetics into particular aspects. They included sensory aspects which are e.g. visual (e.g. transparency) and kinesthetic (e.g. physical effort); and those that are not specific to a sensory modality; which are spatio-temporal (e.g. movement range), action-reaction (e.g. feedback properties) and presentation (e.g. richness in presented information) aspects. In addition to these categories, the context of interaction was also referred as an aspect of interaction. Please see Figure 5.6, which lists the aspects of the infotainment system with **a colour-coding system.**

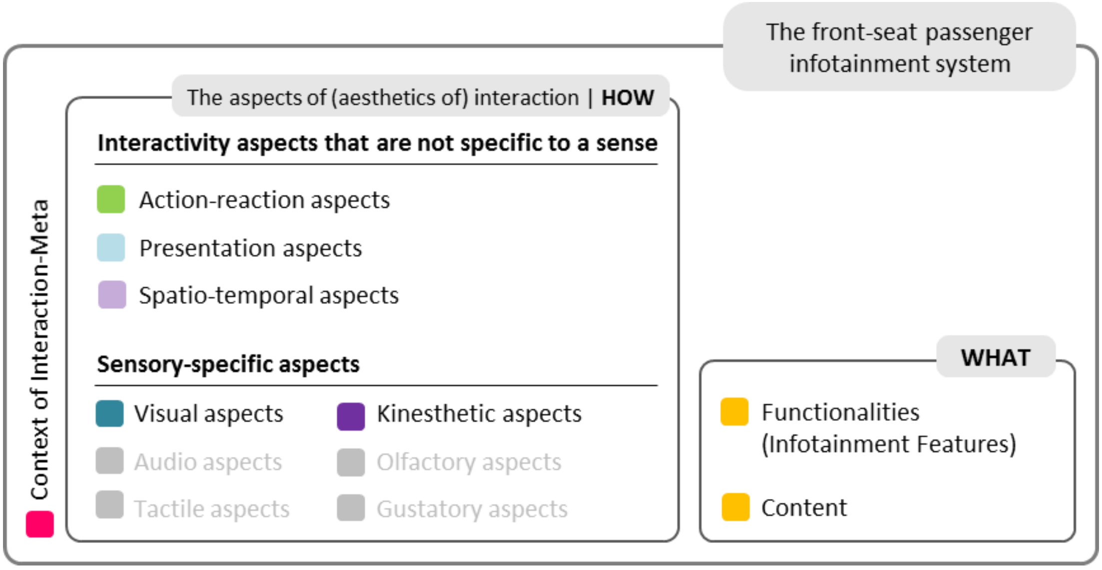


Figure 5.6 Front-seat passenger infotainment system aspects

In Figure 5.6, the audio, tactile, olfactory and gustatory aspects are not colour-coded since design of the infotainment system -therefore the VR simulation- did not intent to provide any interaction that targeted those sensory channels. The interaction tasks in the media menu included playing a list of songs, however, this was not an audio aspect specific to the infotainment system. The tactile aspects of the touch-sensitive button in the design proposal couldn't be included in the analysis either, since it was not always practical to use the VR controller's button when the participants were wearing VR-HMD. Participants' comments regarding the lack of audio/tactile feedback is coded as an action-reaction aspect, since it defined the way the feedback was given.

Although each of the categories under the interaction aspects (e.g. presentation) has its own distinct definition (See Table 2.1), sometimes it was challenging to code participants' comments about the infotainment interactions within a single category. The challenge was observed especially in differentiating the presentation and visual aspects, or spatio-temporal and kinesthetic aspects.

The infotainment system included GUI where the aspects that defined the way information was presented also defined the way the system looked. The challenge of clustering the visual vs. presentation aspects was tackled with coding the related comments under visual aspects rather than presentation aspects, unless there was a more conceptual explanation of the information presentation such as '*definition* of the functionalities with labelled menu icons' or a general explanation like '*richness* in presented information'.

Most of the spatio-temporal aspects of the infotainment system (position of the interactive elements on GUI) defined the way gestures were performed, therefore the kinesthetic experience. However, not every spatio-temporal aspect was experienced kinaesthetically, which can be illustrated with *pop-up directions* that defined the movement of the notification image on HUD. Therefore, there was still a need for two separate categories. In the content analysis of the interview, the comments directly referring to participant's bodily experience such as *physical effort* or *gestural control* were coded as kinesthetic aspects; but other aspects like *the distance between the passenger and TOLED* were coded as spatio-temporal aspects.

In relation to the *what* level of interaction, defining the categories through the list of the functionalities (e.g. media) and relevant content (e.g. song info) was not adequate to cover the participants' comments about the infotainment features. There were also comments regarding the 'variety of functionalities' or 'capabilities of each menu' (functionalities within functionalities).

The importance of the analysis provided in the following sections through the graphs is twofold: First, they demonstrate the variety of the infotainment system aspects that have an influence on the delivery of pragmatic and hedonic qualities of experience and more specifically luxury. Thanks to the deconstruction of the how and what levels of the infotainment system interactions into separate aspects, it is possible to understand exactly which ones were mentioned in relation to being e.g. simple, captivating, involving or luxury (semantic differential pairs used in UX evaluation). Second, they demonstrate the number of participants who mentioned these aspects in relation to these semantic differential pairs, so that we can draw conclusions in terms of which aspect plays the most crucial role in delivery of a pleasant or luxury passenger UX.

5.5.2.1 Pragmatic qualities (functional value) and front seat passenger infotainment system

As mentioned earlier, pragmatic quality (functional value, usability) of the infotainment experience was appraised in UX evaluation questionnaire with the semantic differential pairs that were: i) complicated vs. simple, ii) cumbersome vs. efficient, iii) unruly vs. manageable, and iv) predictable vs. unpredictable. This section will present the interaction aspects and functionalities that were associated with these semantic differential pairs by the participants.

It is important to note that, although the UX evaluation questionnaire results show high ratings for the pragmatic quality, when participants were encouraged to talk about usability, they tended to justify their negative appraisals rather than the positive ones in the follow-up interview. This was expected because talking about usability problems was easier than explaining why the system was usable.

i) Complicated vs. Simple:

As can be seen in Figure 5.7, the infotainment system was found 'complicated' due to the spatio-temporal aspects of the system (e.g. boundary of the movement set by the size/width of buttons/sliders, duration of pointing, and front-seat passenger's distance to the HUD). These were the spatio-temporal aspects that also determined how gestural controls were performed. 'Action-reaction' aspects were also mentioned as part of complications of the infotainment system. These aspects included e.g. the delay in start of the visible colour transition of the buttons in selection feedback, and fixed position and size of the camera frame (limited ability to make changes).

The infotainment system was found as 'simple' mostly because of the way the information was presented visually, such as clear communication of the functionalities through menu icons (4/27) or having access to basic functions from "a place that you'd expect to see them" (P26 on familiarity of the position of the interactive elements) (2/27). Functionality-wise, the variety of infotainment features and the capabilities of each of the menus were mentioned to be perfectly sufficient for the front-seat passenger, as explained by P11:

> There are not load of icons or items on the menu, but there is definitely enough for what should you be a passenger in a car, such as journey information, media and things like that. There were things that people would use when they are in the car so yes, it's…, everything is there in a simple way, so it's not been over-complicated.

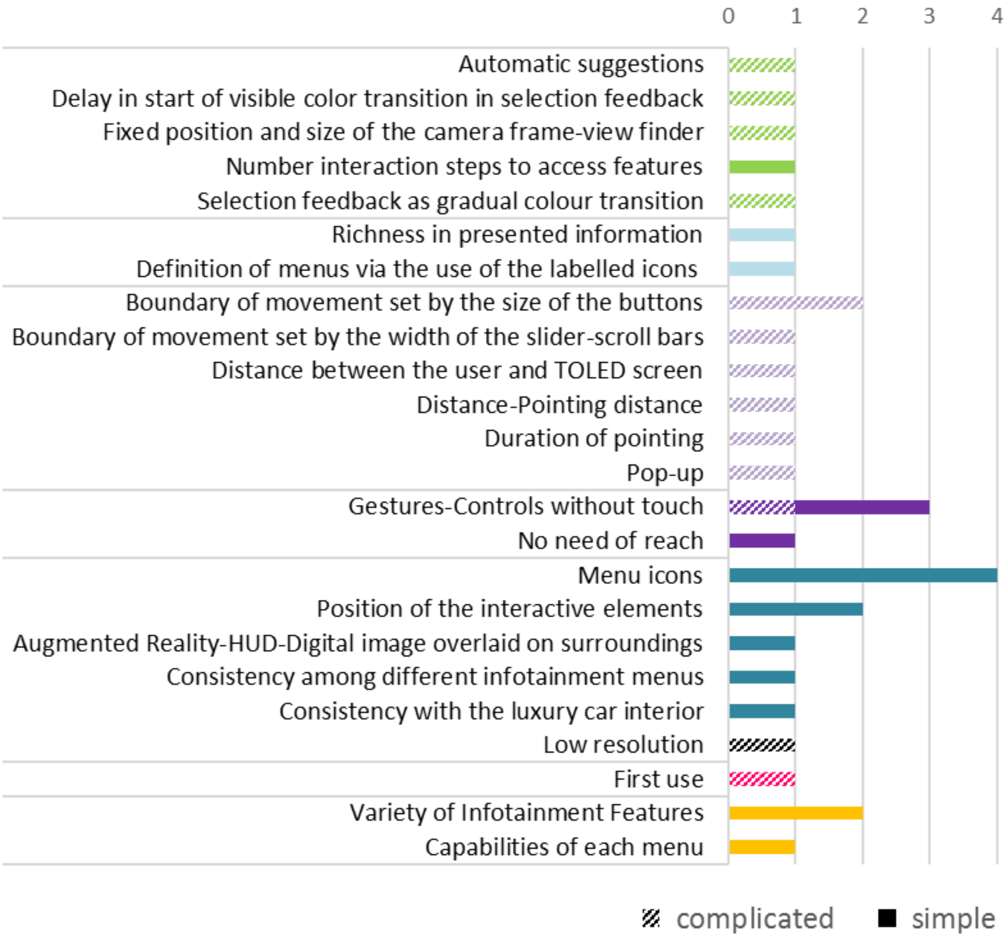


Figure 5.7 Infotainment system aspects that were found to be 'complicated' or 'simple' by the participants

ii) Cumbersome vs. Efficient:

As demonstrated in Figure 5.8, spatio-temporal and kinesthetic aspects of interaction played the biggest role in delivery of the functionalities in an efficient vs. cumbersome way. The inefficiencies can be explained with the challenges in the gestural controls (8/27) and the physical effort needed to perform these controls (4/27). These were mostly connected to the limited boundary of the movement set by the size/width of buttons/sliders (8/27), duration of pointing (found longer than expected by 6/27) and position of interactive elements (e.g. home button at the far corner, 4/27). The results show that some 'visual aspects' of the GUI (e.g. size of the buttons) do not only affect the way the interface looks/communicates information; but also, the users' kinesthetic experience when the system is controlled with gestures.

There were some participants (P5, P15, P26) who regarded the gestural controls as efficient means of input, since 'they eliminated the issue of reaching somewhere in the car to control the system'. In terms of action-reaction, automatic suggestions were appreciated as being efficient by 3 out of 27 participants, as they eliminated the need of pulling information from the system. For similar reasons, pop-ups were also found to be efficient (3/27).

Other aspects of the infotainment system found to be 'cumbersome' or 'efficient' can be seen in Figure 5.8.

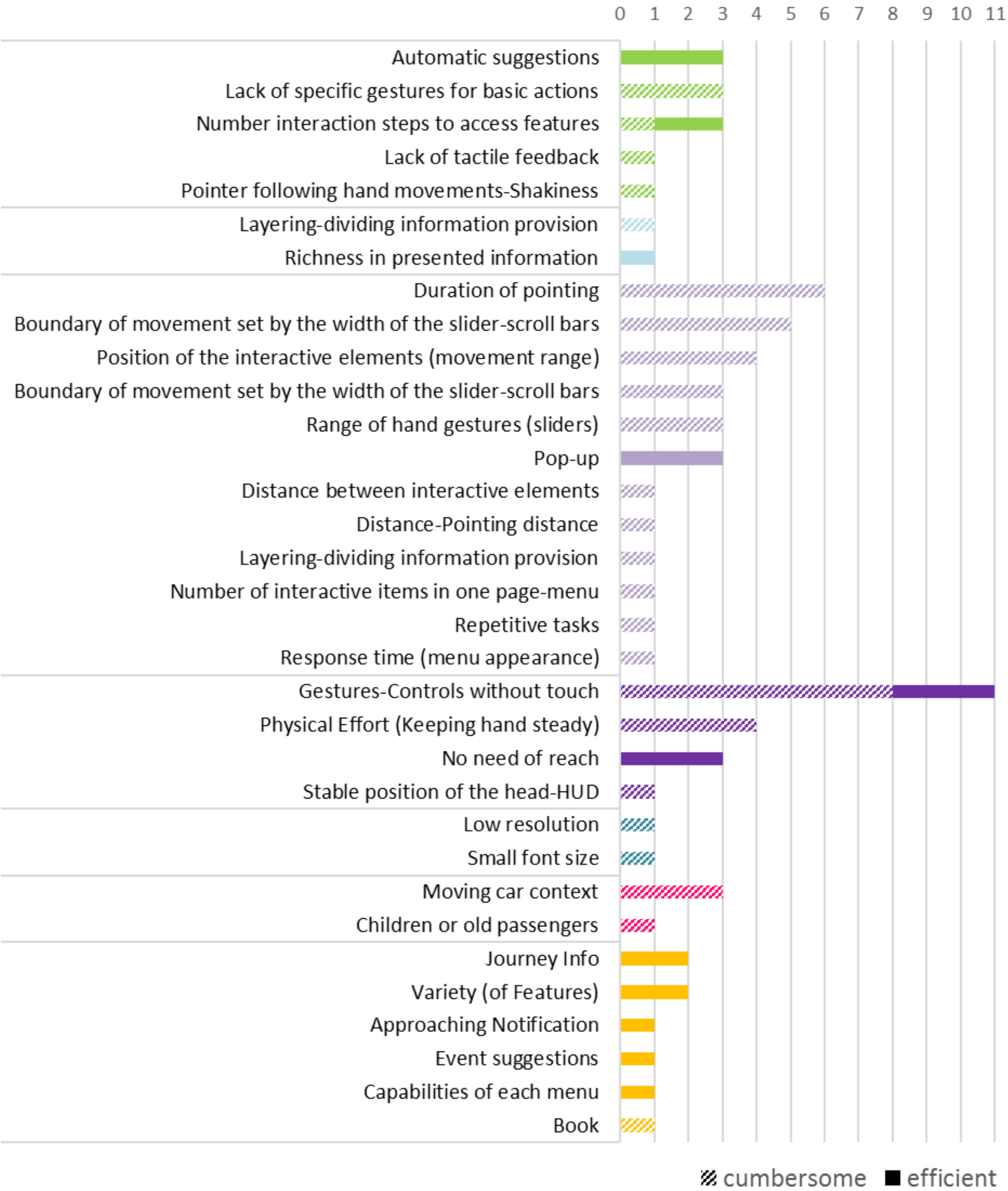


Figure 5.8 Infotainment system aspects that were found to be 'cumbersome' or 'efficient' by the participants

iii) Unruly vs. Manageable:

Figure 5.9 shows that most of the infotainment system aspects that the participants mentioned for ‘cumbersome vs. efficient’ were also repeated for ‘unruly vs. manageable’. The most ‘unruly/hard to manage’ aspects were identified as gestural controls (9/27) and the spatio-temporal aspects that defined how gestural input was provided (e.g. limited boundary of the movement set by the size/width of buttons/sliders).

On the other hand, the (limited) variety of infotainment features (functionalities) was said to be manageable by 3 out of 27 participants.

Other aspects of the infotainment system that were found to be ‘unruly’ or ‘manageable’ can be viewed in Figure 5.9.

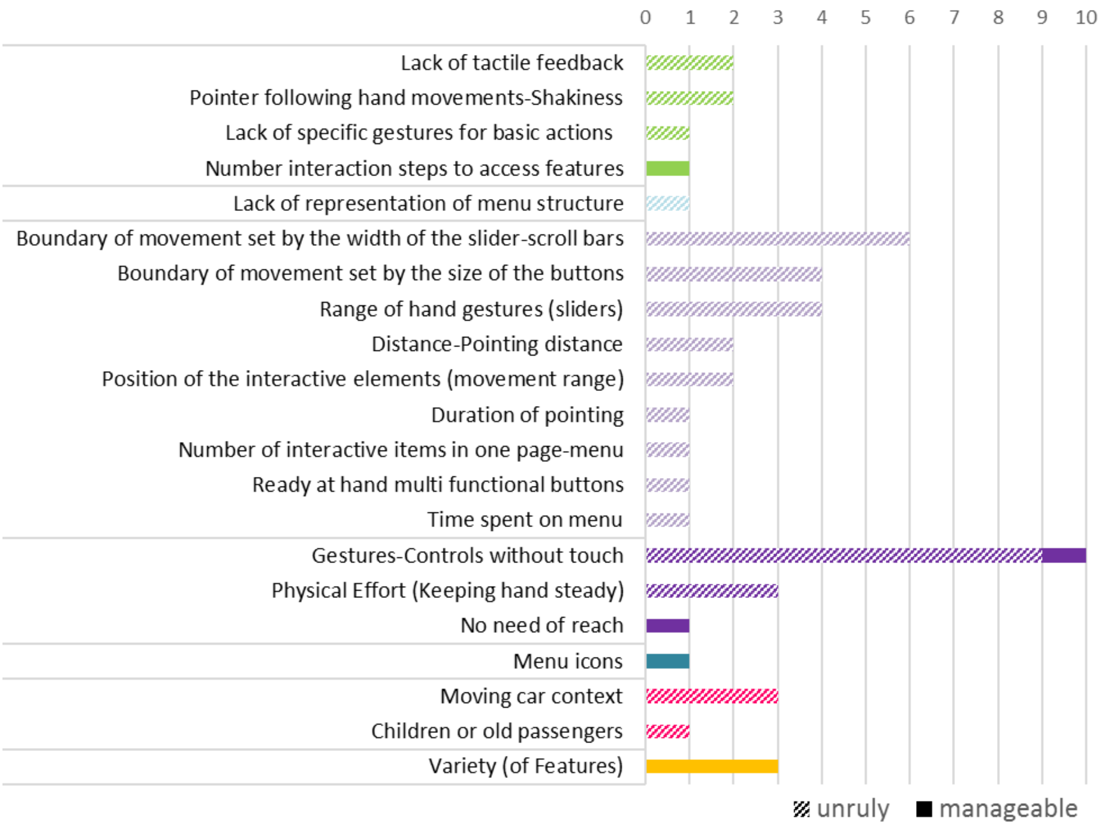


Figure 5.9 Infotainment system aspects that were found to be ‘unruly’ or ‘manageable’ by the participants

iv) Unpredictable vs. Predictable:

During the follow-up interview, when participants were asked the ‘unpredictable vs. predictable’ aspects of the infotainment system, they sometimes referred to unpredictability as a positive quality of experience and used the term in place of being surprising, as a means of stimulation. Therefore, Figure 5.10 shows ‘unpredictable’ aspects that were associated with both surprise (as a positive appraisal) and with weak usability.

The surprising aspects were mostly related with the way notifications are provided to front-seat passengers (e.g. augmented reality, pop-up, automatic suggestions, arrival notification). Other aspects of the infotainment system that were found to be surprising can be seen in Figure 5.10.

As predictability is about anticipating how the system will be used and how it will react to user's input, action-reaction aspects were also referred in predictability appraisals. The results show that the unpredictable aspects were not specific to one particular category of infotainment system aspects. Regarding action-reaction, the lack of feedback in other modalities than the visual (2/27) and lack of 'clickable' visuals in journey info menu (2/27) caused the system to be unpredictable for the participants. Regarding presentation, it was challenging to predict that there was a match between the playlist songs in media menu and the destinations (2/27), which was offered to be calculated based on the remaining distance, speed of the car and the duration of the songs.

The spatio-temporal aspects that were hard to predict were related with the interaction aesthetics of the notifications (e.g. frequency of the notifications, pop-up, pop-up directions). In addition, one participant (P27) claimed that the distance between the TOLED and the user was not far enough for user to anticipate that there was a need to control the system without touching it.

Other aspects of the infotainment system that were found to be 'unpredictable' can be viewed in Figure 5.10.

Predictable aspects of the system were mentioned as clear menu icons (2/27) and use of labelled icons (definition of functionalities) (1/27). One participant also referred to the selection feedback (the gradual colour transition of the buttons) as a predictable aspect since it was able to communicate the required duration of the pointing for activation.

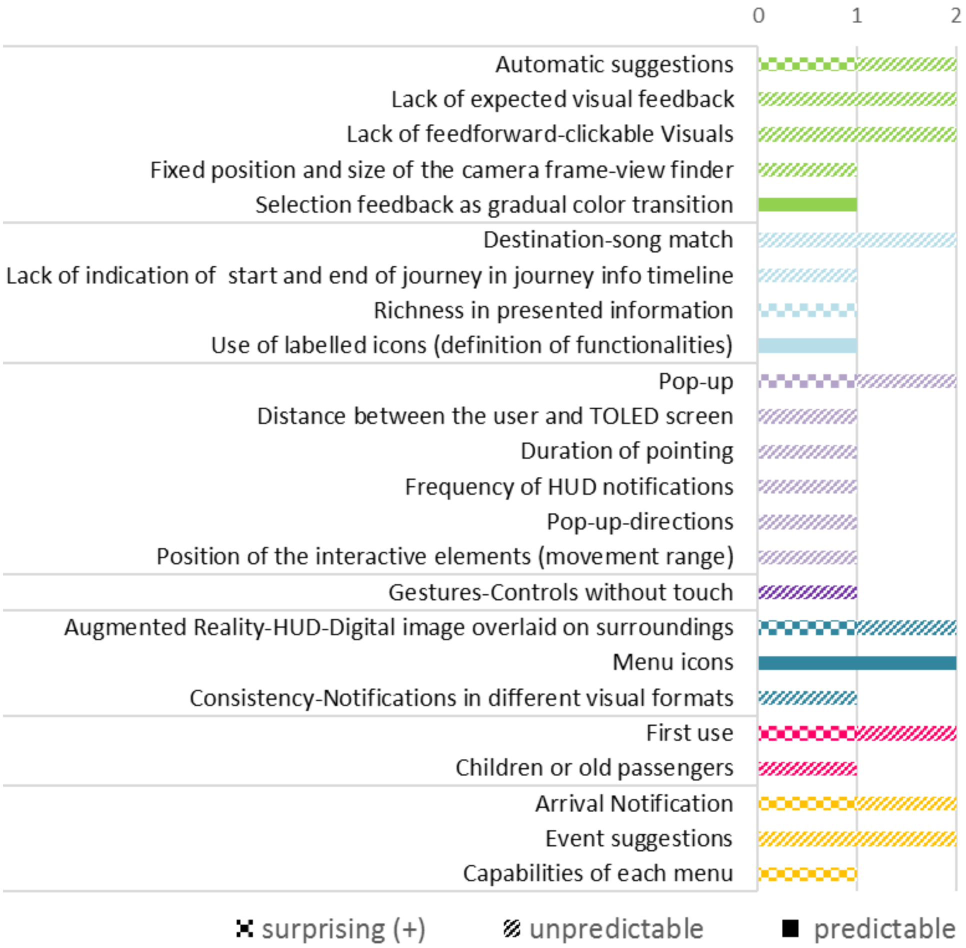


Figure 5.10 Infotainment system aspects that were found to be 'surprising', 'unpredictable' or 'predictable' by the participants

5.5.2.2 Stimulation (hedonic qualities-experiential value) and front seat passenger infotainment system

Stimulation, defined as a dimension of the hedonic quality of user experience (experiential/individual value), refers to provision of new impressions, opportunities and insights (Hassenzahl, 2003). In this research, stimulation of the infotainment experience was appraised in UX evaluation questionnaire with the semantic differential pairs. The pairs were: i) conservative vs. innovative, ii) usual vs. extraordinary, iii) cautious vs. bold, and iv) dull vs. captivating. This section will present the interaction aspects and functionalities that were associated with these semantic differential pairs by the participants.

i) Conservative vs. Innovative:

The results show that most of the participants associated innovation with the aspects of interaction that were determined by the embodied interaction technologies offering new sensory experiences. As can be seen in Figure 5.11, the innovative aspects involved the kinesthetic and visual aspects. The innovative kinesthetic aspects were mentioned as use of gestures / controls without touch (11/27). The innovative visual aspects included augmented reality through the HUD (10/27) and the transparency of the TOLED (4/27).

Among the functionalities provided in the system, 8 out of 27 participants found the camera as the most distinct feature distinguishing this system from currently available infotainment systems.

There was not a specific aspect of the infotainment system that needs to be highlighted amongst others regarding being conservative. Other aspects of the infotainment system that were found to be innovative or conservative can be seen in Figure 5.11.

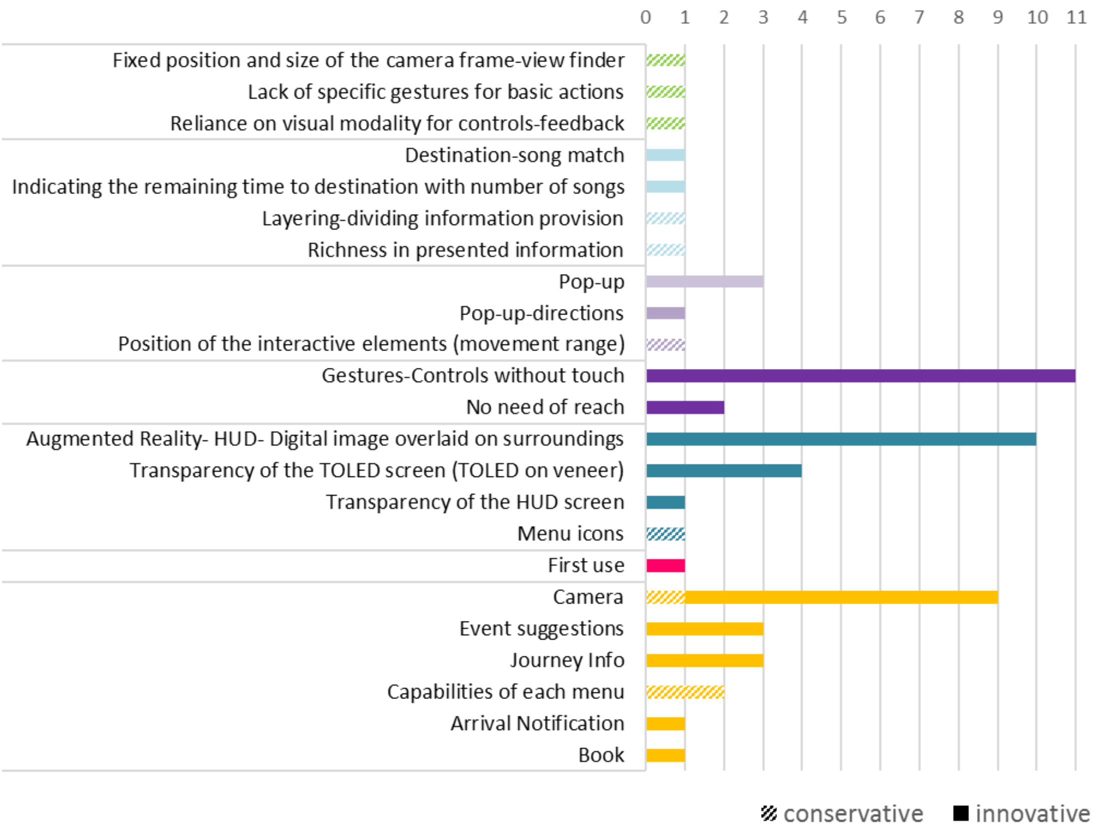


Figure 5.11 Infotainment system aspects that were found to be ‘conservative’ or ‘innovative’ by the participants

ii) Usual vs. Extraordinary:

Figure 5.12 demonstrates that the innovative aspects of the infotainment system were also found to be extraordinary. In addition to the use of AR (8/27), TOLED screen (5/27) and gestural controls (7/27), other two most extraordinary interaction aspects were automatic suggestions (3/27) and layering/dividing information provision to two screens (2/7). Functionality-wise, as mentioned for the semantic differential ‘innovative vs. conservative’, camera was also referred as an extraordinary infotainment feature. Journey info and media were not found extraordinary enough for being more similar features to the ones provided in available infotainment systems for drivers. However, P8 appreciated the front-seat passenger's convenient access to the most necessary journey information and referred to journey info as an extraordinary feature as well.

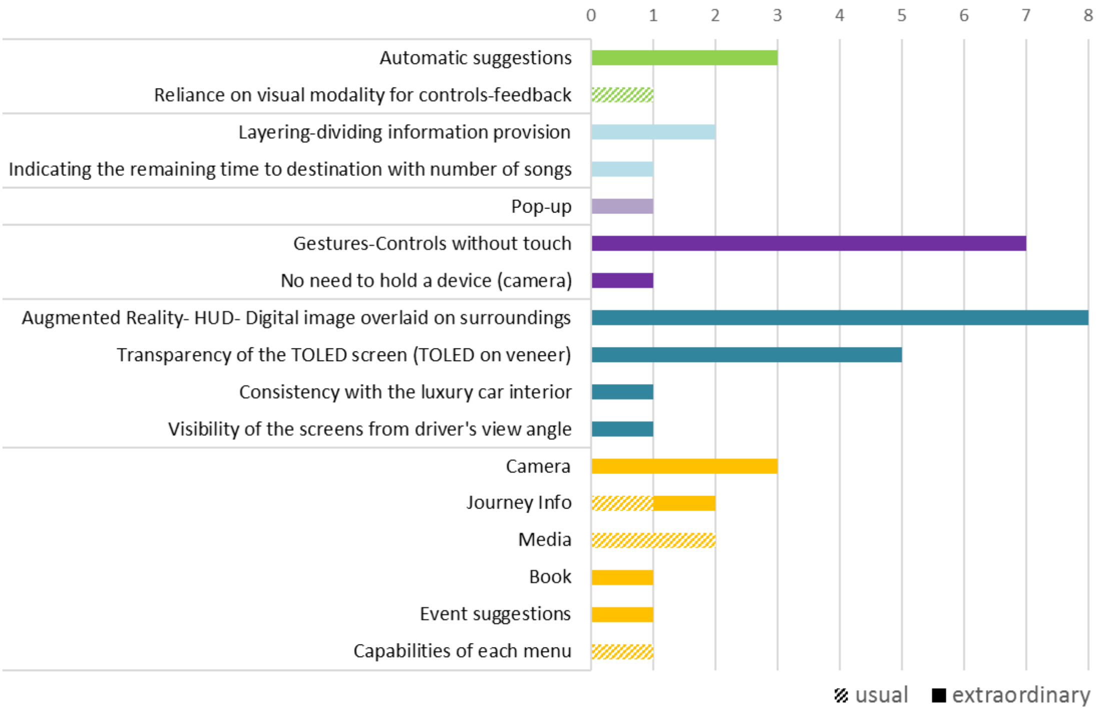


Figure 5.12 Infotainment system aspects that were found to be 'usual' or 'extraordinary'

iii) Cautious vs. Bold:

As can be seen in Figure 5.13, the infotainment system aspects that were mentioned to be 'cautious vs. bold' were more limited in number compared to other semantic differential pairs. Participants felt difficulty in defining boldness with regards to their infotainment system experience, therefore the quantitative analysis was limited due to the number of responses.

As mentioned earlier whilst explaining the scope of the prototype, the content and number of interaction steps for each functionality were limited in VR simulation. As a result, the most cautious aspect was mentioned to be the capabilities of each menu by 2 out of 27 participants.

According to the research participants, the boldest interaction aspects of the infotainment system included transparency of TOLED screen (3/27), augmented reality (2/27), gestural controls (controls without touch) (2/27) and automatic suggestions (2/7). Regarding the gestural controls, P18 mentioned that "To manipulate everything without contact was brave." In terms of functionality, event suggestions were highlighted amongst other functionalities for being bold. It can be also seen that other bold interaction aspects (e.g. automatic suggestions, pop-up, size of the HUD notifications) were also related with the delivery of the event suggestions functionality.

Other aspects of the infotainment system that were found to be cautious or bold can be seen in Figure 5.13.

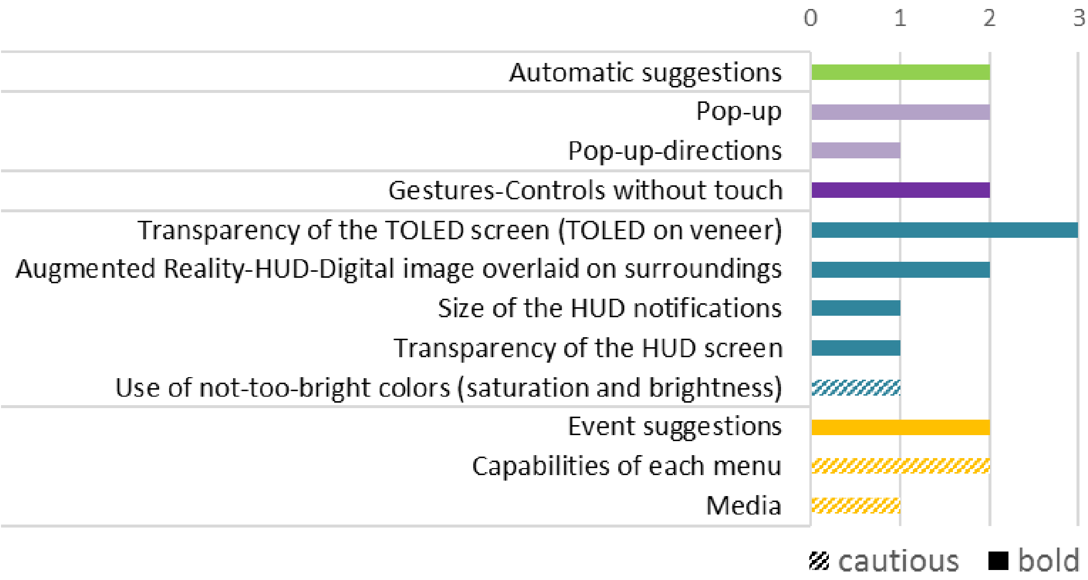


Figure 5.13 Infotainment system aspects that were found to be 'cautious' or 'bold'

iv) Dull vs. Captivating:

As can be seen in Figure 5.14, the number of infotainment system aspects that were found to be dull by the participants are very low compared to the ones that were found to be captivating.

The captivating infotainment experience was mostly associated with the infotainment features/functionalities the system provided. Among these functionalities, being able to capture the images of the surroundings through camera (7/27) and finding the answers of travel-related questions through journey info (6/27) were highlighted as the two most captivating infotainment features.

In terms of the way the users interact with the system, the most captivating interaction aspect was defined as the use of AR.

Other aspects of the infotainment system that were found to be 'dull or captivating' can be seen in Figure 5.14.

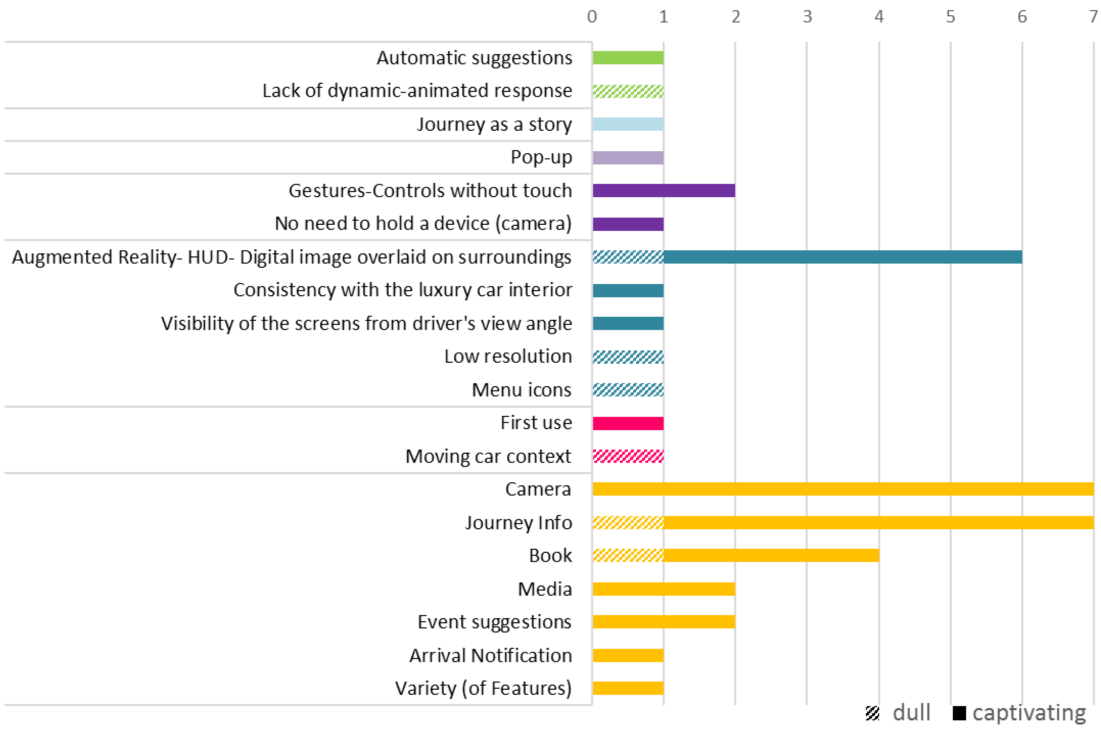


Figure 5.14 Infotainment system aspects that were found to be 'dull' or 'captivating' by the participants

5.5.2.3 Identification (hedonic quality) and front-seat passenger infotainment system

Identification, defined as another dimension of the hedonic quality of user experience, refers to communicating an identity (Hassenzahl, 2003). Identification also relates to the symbolic value / social value of luxury experience, implying the socially constructed meaning of a luxury product. In this study, identification of the infotainment experience was appraised in UX evaluation questionnaire with the following semantic differential pairs: i) alienating vs. involving, ii) low-quality (unrefined) vs. high quality (refined), iii) tacky vs. stylish, and iv) unpresentable vs. presentable. This section will present the interaction aspects and functionalities that are associated with these semantic differential pairs by the participants.

i) Alienating vs. Involving:

The semantic differential pair 'alienating vs. involving' was included in the questionnaire to measure whether the system can deliver social value. However, in the follow-up interview, when participants were asked about the 'alienating vs. involving' aspects of the infotainment system, it was observed that they approached 'involvement' in several other ways. This included the following three approaches, on which the analysis was based:

a) Involvement 'in social interactions with the other car occupants'

b) Involvement 'in the journey'

c) Involvement 'in the use of the system'

a. Involvement in social interactions with the other car occupants:

Regarding 'involvement in social interactions with the other car occupants' (see Figure 5.15), 4 out of 27 participants had some concerns about using the book feature. For example, P24 mentioned:

> I probably wouldn't use the book, and the reason being that it feels anti-social, because I think if you are driving with someone you know, it makes a bit difficult to use things that are just for yourself.

Conversely, P12 and P20 identified camera and journey info features as possible secondary tasks for drivers to be taken care by the front-seat passenger. Therefore, they appreciated these features as the facilitators of collaboration among the front-seat occupants.

Involvement in social interactions with the other car occupants requires sparing time for the communication. Therefore, 3/27 participants had concerns about 'the time spent on the menu', since the involvement in the use of a system for a long time could be alienating from other car occupants (which can be preferable considering driver distraction). The way notifications were provided (automatic suggestions as pop-up menus on HUD covering passenger windscreen) was also found to be a bit alienating, as it can create distraction for the passengers when they are involved in conversation with the driver or co-navigate. One participant (P8) stated that:

> The pop-up window blocks your view, it kind of hinders your vision of the road which might be helpful in terms of accidents or like other stuff.

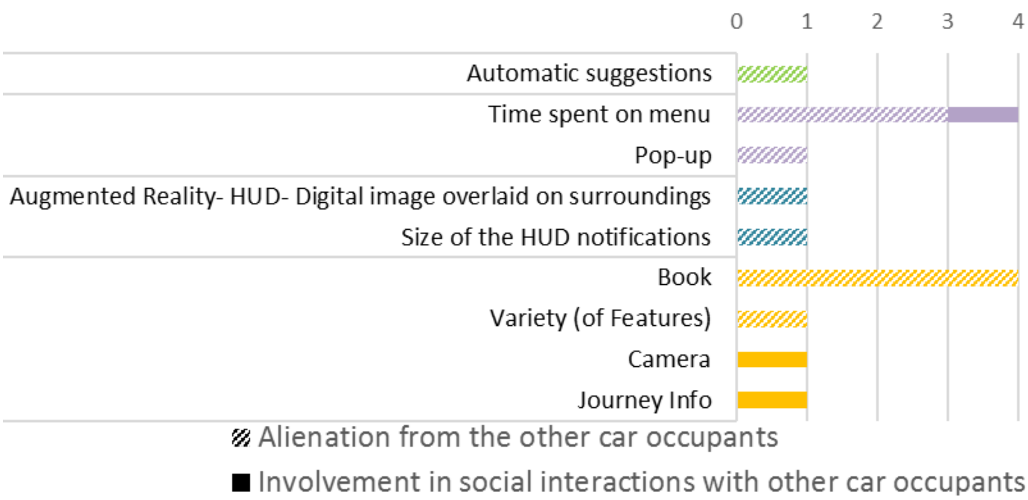


Figure 5.15 Infotainment system aspects and involvement in social interactions with the other car occupants

b. Involvement in the journey:

Regarding 'involvement in journey' (see Figure 5.16), camera (5/27), journey info (5/27) and arrival notifications (1/27) were claimed to be the features connecting the front-seat passengers to journey since they were all about documenting / reviewing / getting informed about the journey. There was not a consensus over whether the event suggestions were 'involving vs. alienating'. The results showed that, depending on its interaction aesthetics, the event suggestions feature can be regarded as a spam that may alienate the passenger from the journey, or as a means of stimulation that may keep the passenger informed, hence, involved in the journey. In this regard, the critical interactions aspect are/were; action-reaction (automatic suggestions), spatio-temporal (frequency of HUD notifications, pop-ups) and the visual (use of AR, size of HUD notifications) aspects.

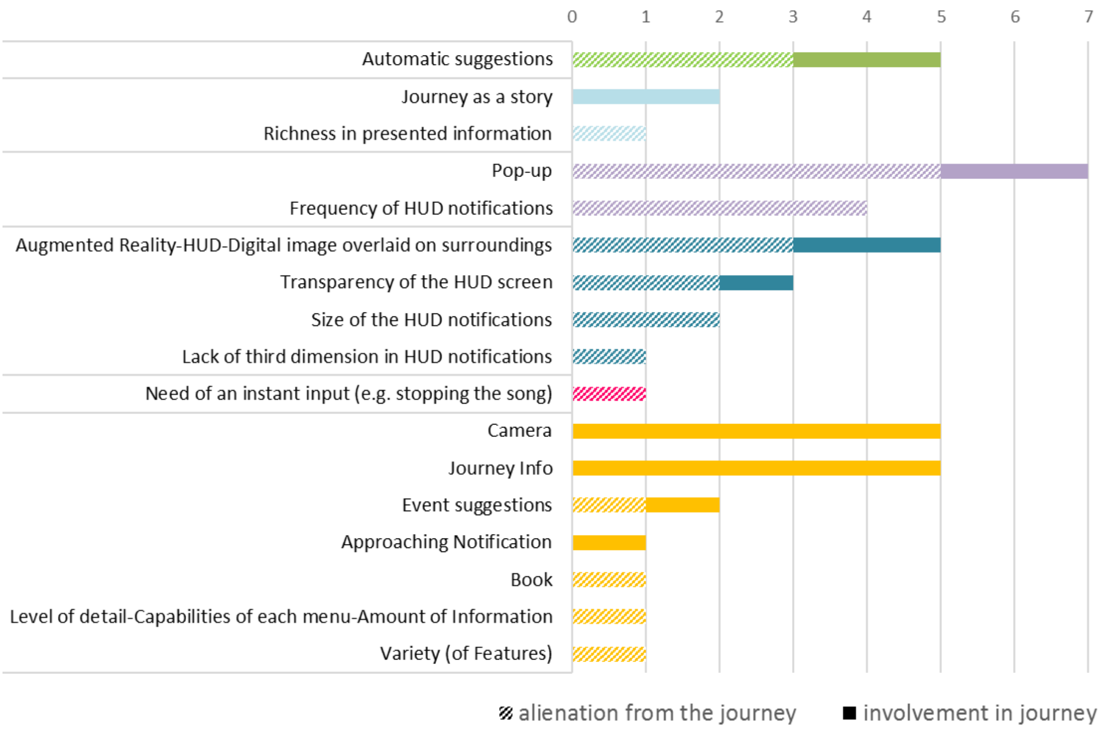


Figure 5.16 Infotainment system aspects and involvement in the journey

c. Involvement in the use of the system:

As shown in Figure 5.17, some participants mentioned that the pop-ups (5/27), frequent notifications (4/27) and automatic suggestions (3/27) could prevent them from being involved in the use of the infotainment system (in use of other infotainment features than notifications).

In comparison with involvement in journey or in social interactions with other car occupants, it was observed that 'involvement in the use of the system' was more related with action-reaction aspects of the infotainment system. For example, P17 stated that the lack of feedback in other modalities than the visual made the system more alienating than involving. Another concern regarding the involvement was identified as lack of conversation as claimed by P23:

> …would be more involved if it was more of a… 'We are here now, and this is interesting because if you look to your left, there is something.' So, I don't know, '-There is this thing at Connaught, would you like to go? -Yes, I would', and it could keep you involved, like saying, - Here is the menu, and it needs a reservation, would you like me to reserve your spot. I can place your order if you want. Once you are finished with this there is a quite nice antique shop', you know… The way it is presented is quite transactional isn't it? Here you are. Do you want to do this? There is no follow-up richness.

Low resolution of the text in GUI was also mentioned by 2/27 participants as a visual aspect that alienated them from being involved in the system. It is also important to mention that low resolution was a VR-related limitation, not a design decision.

Other aspects of the infotainment system that were found to be 'alienating vs involving' (regarding the use of the system) can be seen in Figure 5.17.

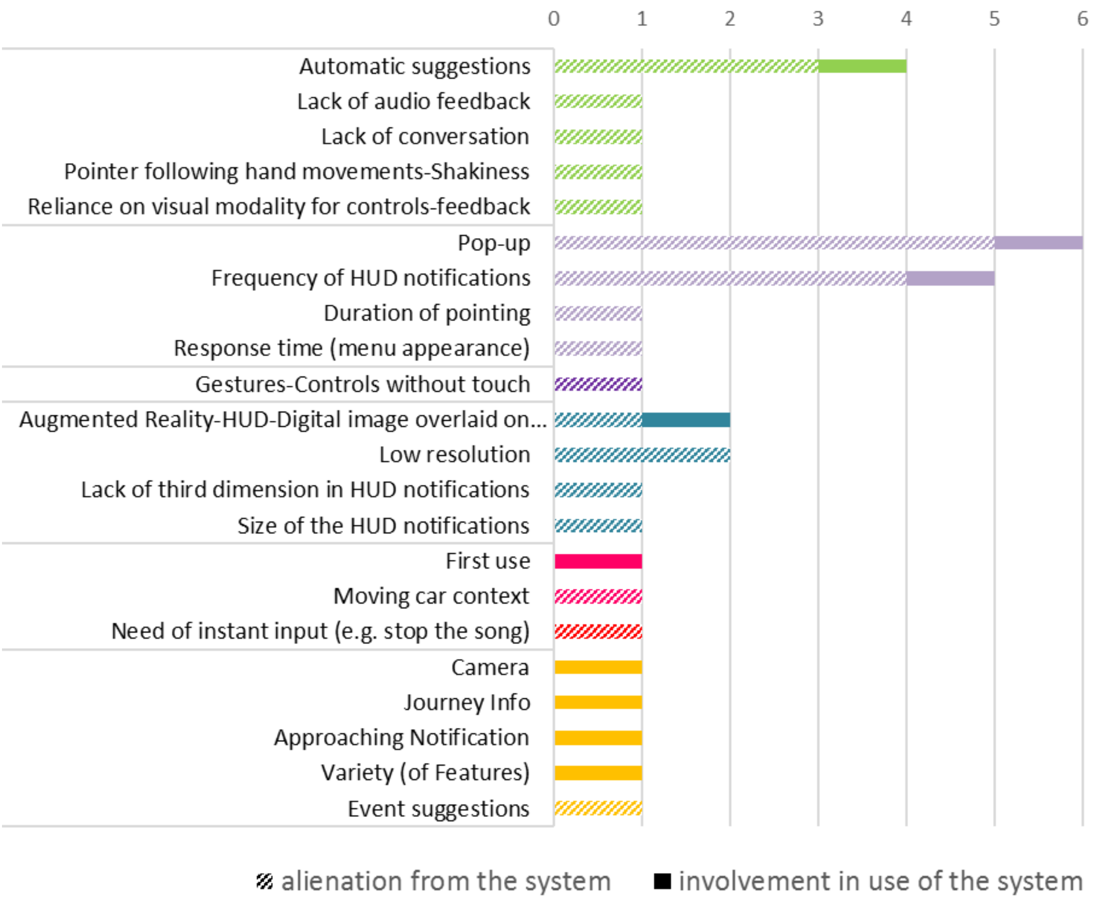


Figure 5.17 Infotainment system aspects and involvement in the use of the system

ii) Low quality (unrefined) vs. High quality (refined):

As can be seen in Figure 5.18, 9 out of 27 participants referred to gestural controls as the key aspect of the system that affected quality appraisals. Accordingly, three participants (P3, P5 and P19) claimed that the ability to control the system without physical means was an indicator of high quality, whereas the remaining six participants thought that gesture tracking challenges lowered the quality of their experiences. With regards to low quality, participants also identified the spatio-temporal aspects that caused challenges in gestural controls (e.g. boundary of the movement set by the size/width of buttons/sliders) (See Figure 5.18). According to 3 out of 27 participants the lack of specific gestures for basic actions (e.g. swiping hands to advance pages in book menu), was as one of the action-reaction aspects that lowered the quality of infotainment experience.

In relation to the 'low quality vs. high quality' semantic differential pair, the second most referred interaction aspects were the visual ones. The use of AR (4/27) and the menu icon design (3/27) were appreciated as high-quality visual aspects. However, the low resolution (6/27) and the size of the TOLED which was restricted by the size of passenger dashboard (2/7) were claimed to be low-quality visual aspects of the system.

Regarding the functionalities, 4 out of 27 participants also expressed their quality-related concerns through the limited capabilities of the menus (e.g. need of more information at arrival notification, more adjustment options in camera). However, it should be recalled that most of the infotainment feature capabilities deliberately went through a limitation within the scope of the VR simulation.

Other aspects of the infotainment system that were found to be 'low quality or high quality' can be seen in Figure 5.18.

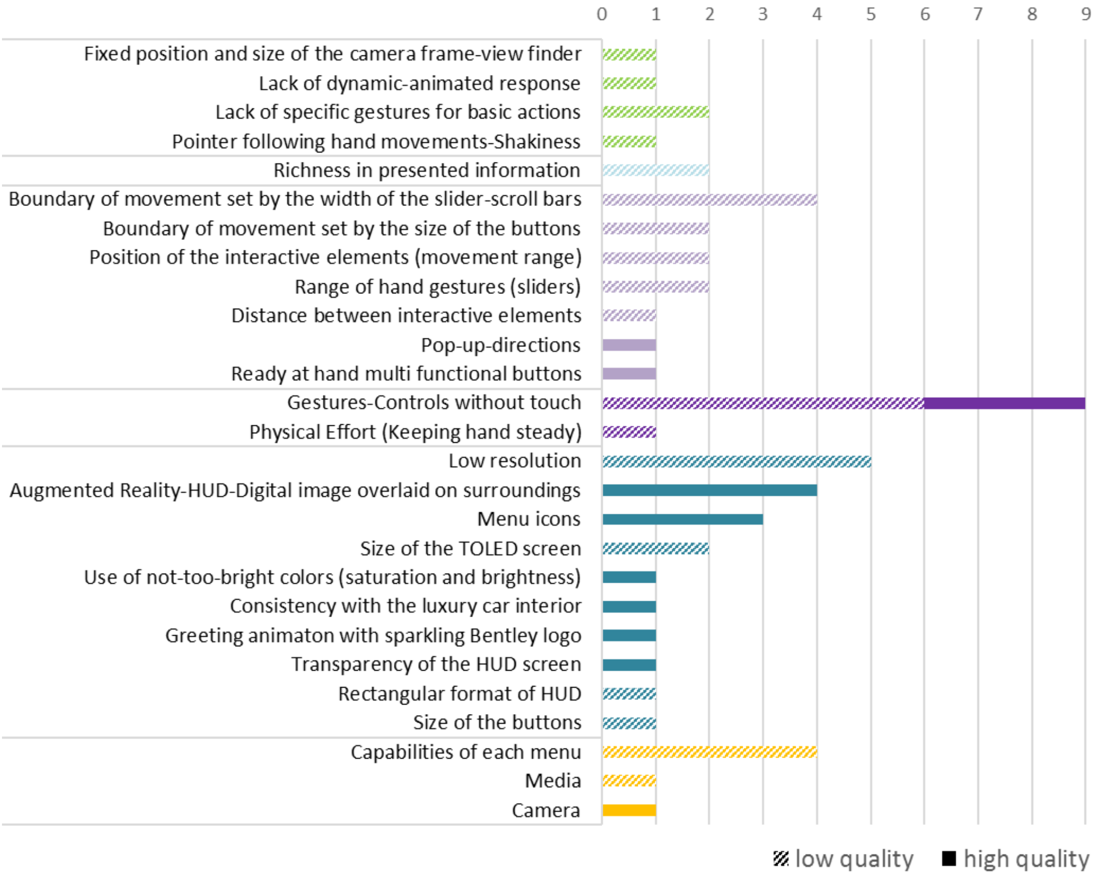


Figure 5.18 Infotainment system aspects that were found to be 'low quality' or 'high quality' by the participants

iii) Tacky vs. Stylish:

Being tacky vs. stylish was strongly associated with the visual aspects of the infotainment system by the participants. These visual aspects 'celebrated' or were consistent with the 'luxury' materials or interior of the car such as the passenger dashboard with the handcrafted wooden veneer. For example, use of TOLED on passenger dashboard did not hinder but revealed the 'luxury' material through transparency (7/27). In addition, the consistency of GUI with interior (7/27) was appreciated as a stylish aspect.

Other aspects of the infotainment system that were found to be 'tacky or stylish' can be seen in Figure 5.19.

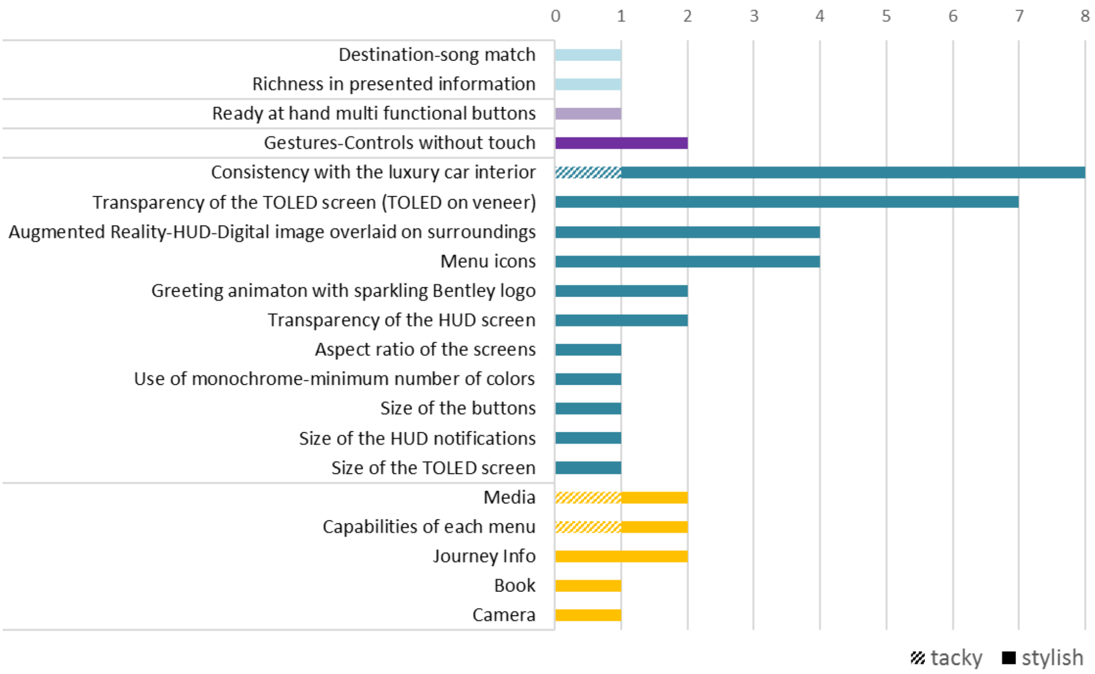


Figure 5.19 Infotainment system aspects that were found to be ‘tacky’ or ‘stylish’ by the participants

iv) Unpresentable vs. Presentable:

It was observed that there were several interaction aspects that were found to be both presentable and stylish or unpresentable and tacky. This shows that the participants defined ‘presentability’ mostly through visual aspects that were listed in Figure 5.20. However, for this specific semantic differential pair that appraises presentability, they also referred to the action-reaction (e.g. shakiness of the pointer) and the spatio-temporal aspects of interaction (e.g. boundary of the movement set by the width of the sliders) that also affected the usability of the gestural controls.

Other aspects of the infotainment system that were found to be ‘unpresentable or presentable’ can be seen in Figure 5.20.

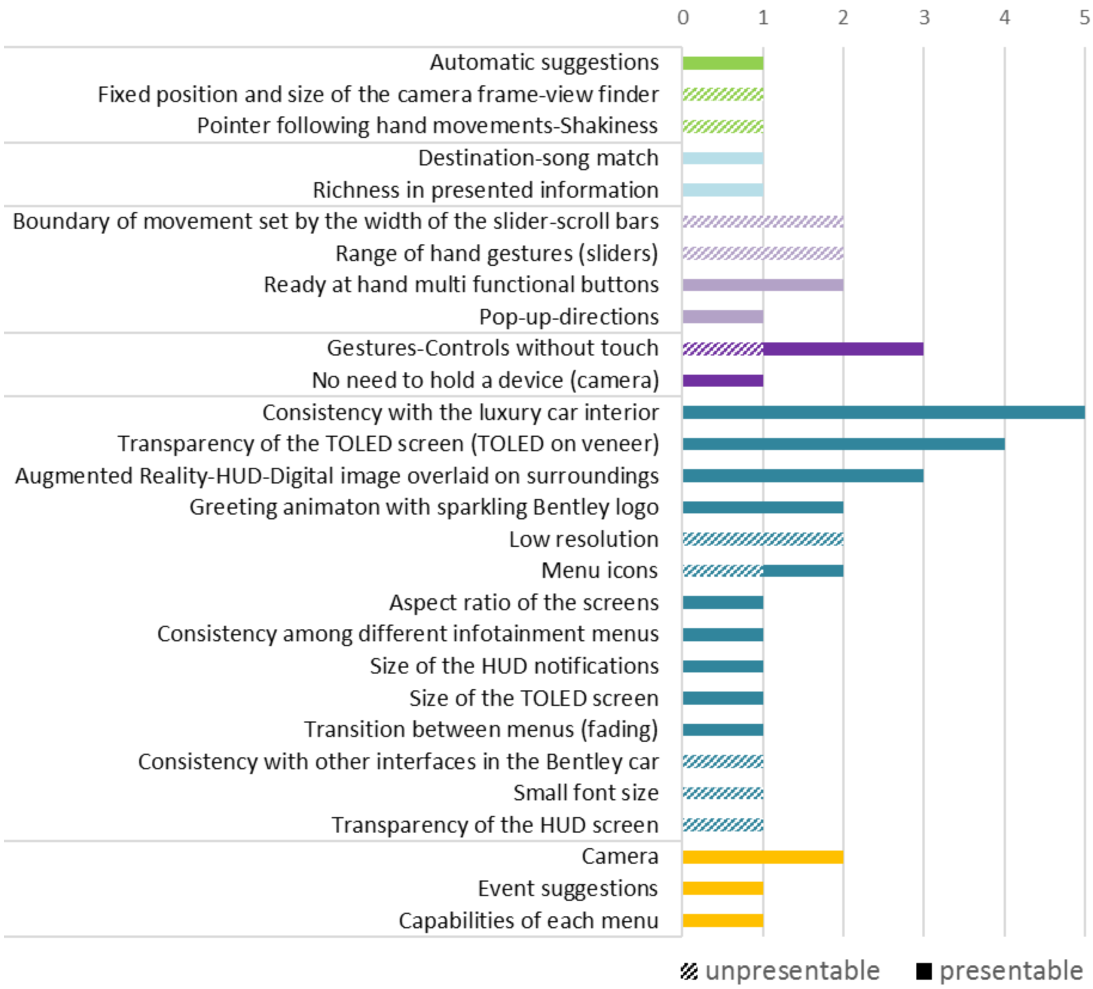


Figure 5.20 Infotainment system aspects that were found to be 'unpresentable or presentable'

5.5.2.4 Additional qualities of experience

In the follow-up interview, the participants made use of a series of concepts/keywords to describe their experience when asked to justify their ratings for each semantic differential pair in the UX questionnaire. For example, when they were talking about how simple the system was, they mentioned that the position of the basic interactive elements (e.g. home/back button at the top corner) was found to be familiar with other digital interfaces that they knew/experienced. Therefore, in this example, the simplicity cannot be explained only with the spatial organization of the interactive elements, we need to refer to the *familiarity* of this spatial organization to the users to understand why the system is/was simple.

This section compiles such concepts/keywords that the participants utilized while discussing the infotainment system with regards to the pragmatic quality (functional value), hedonic quality of stimulation (as part of experiential value), and hedonic quality of identification (symbolic/social value). These are the qualities of experience for which semantic differentials are defined in the literature. The follow-up interview with the participants also revealed several additional concepts / qualities of experience which cannot be put under any of the listed categories. Table 5.3 compiles and categorizes all the concepts/keywords under the heading of “additional qualities of experience suggested by the participants”.

Table 5.3 Additional qualities of experience suggested by the participants

Additional Qualities of Experience: Keywords/concepts to define expectations from a pleasant UX
Pragmatic Qualities
• Accuracy • Anticipation (of the front-seat passenger’s needs) • Clarity • Communication of how system works • Convenience (e.g. accessing features right away-through car displays) • Being inclusive • Being informative • Level of control (Ability to change-make decisions) • Saving time • Being self-explanatory - No need of instruction • Similarity-Familiarity (positive)
Hedonic-Stimulation Qualities (additional)
• Being attention-grabbing • Discovery • Enjoyability • Being eye-catching • Greeting • Non-intrusiveness • Novelty • Similarity-Familiarity (negative) • Being state-of-the-art • Surprise • Targeting of the front-seat passenger • Well spent travel time-Keeping the passenger occupied
Hedonic-Identification Qualities (additional)
• Relatedness-Social Network • Collaboration
Miscellaneous
• Capturing Moments-Memories • Safety-Security • The cost of embodied technologies (Financial Value)

5.5.2.5 Concerns and challenges about the infotainment system

Section 5.5.2.4 presented the list of qualities of pleasant user experience as suggested by the participants that helps us to understand the expectations from the infotainment system. To have a better understanding of the infotainment experience of the participants it is also essential to consider the concerns and challenges raised by them. For example, the reason why the use of AR was not appreciated for the involvement in social interactions with the other car occupants was participants’ concern about *being prevented from co-piloting.*

Table 5.4 compiles the list of challenges and concerns that played a role in negative appraisals of the front-seat passenger infotainment system, which were mentioned throughout the interview. Categorization of these concerns and challenges in Table 5.4 follows a similar pattern as categorization of the additional qualities as shown in Table 5.3. This list in Table 5.4 will also be referred in the section that discusses the participants' suggestions most of which aim at bringing a solution to a specific concern or challenge regarding the infotainment system.

Table 5.4 Concerns and challenges

Concerns & Challenges
Pragmatic concerns
• Accidental selections (Difficulties in not to select something) • Data Storage-Allowance-Transfer of Media • Division of attention (between HUD and TOLED) • Division of attention (between HUD and travel context) • Driver distraction • Energy efficiency • Failing to take infrastructure info into account • Gesture tracking challenges • Possibility to miss the notifications • Preventing passenger from co-piloting • Readability
Hedonic-stimulation concerns
• Keeping up with the technology-product lifecycle • Passenger distraction • Similar features that exists in car infotainment systems • Similar features that exists in smart phones
Hedonic-identification concerns
• Communication of event suggestions to driver • Irrelevant event suggestions • Preventing passenger from co-piloting
Miscellaneous
• Fatigue-physical discomfort • Motion sickness-Nausea • Protection of privacy of each front-seat occupant within the car • Protection of privacy • Protection of privacy of others

5.5.2.6 Luxury and front-seat passenger infotainment system

Non-luxury vs. luxury

The final semantic differential pair in the questionnaire was set as "[My infotainment experience fails to answer my expectations from a luxury car.] vs. [My infotainment experience answers my expectations from a luxury car.]". By not framing the semantic differential pair as direct as non-luxury vs. luxury, this study aimed to avoid the negative connotations of luxury (e.g. unnecessary). This section will present the infotainment system aspects that answers or fails to answer the participants' expectations from a luxury infotainment experience. The results show that the luxury infotainment system aspects are mostly related with the new sensory experiences through gestural controls (kinesthetic), AR and transparency level of TOLED (visual). It was also observed that the use of any content or interacting with the system in any context that was already associated with luxury (e.g. greeting animation with Bentley logo, starting and ending the journey in luxury locations, event suggestions in luxury venues, etc.) also played role in luxury experience of the infotainment system. It was interesting that one participant (P26) appreciated the gestural control as a luxury aspect since interacting with the system without touching wouldn't leave any fingerprints on the screen (TOLED) and thus retain its luxury look. Although the number of references to the functionalities was limited in luxury appraisals, two participants mentioned that they would have expected the system to offer more capabilities in each menu to be regarded as luxurious.

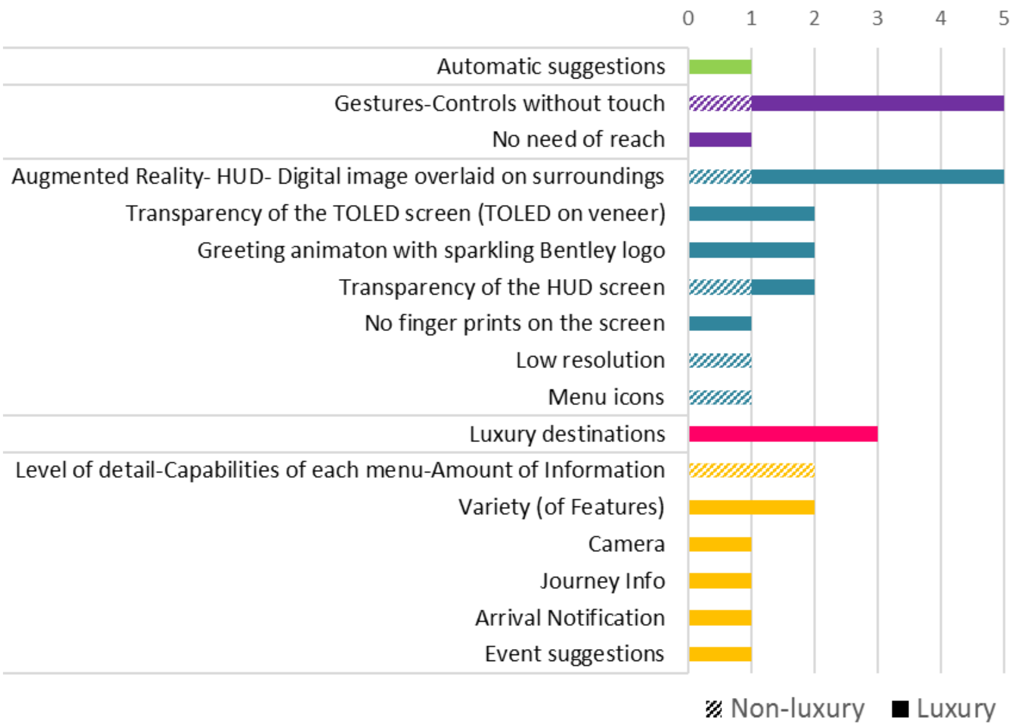


Figure 5.21 Infotainment system aspects that were found to be 'non-luxury' or 'luxury' by the participants

Luxury and the Qualities of Experience

This section articulates what i) experience qualities (the semantic differential pairs in UXQ), ii) additional qualities of experience (listed in Section 5.5.2.4), and iii) the user concerns and challenges the participants highlighted while describing 'luxury vs. non-luxury' experience. This articulation was made possible with the matrix query feature of NVivo software, which searched for the number of the participants mentioning the concept of luxury by referring to one of the listed items. Please see the results in Figure 5.22.

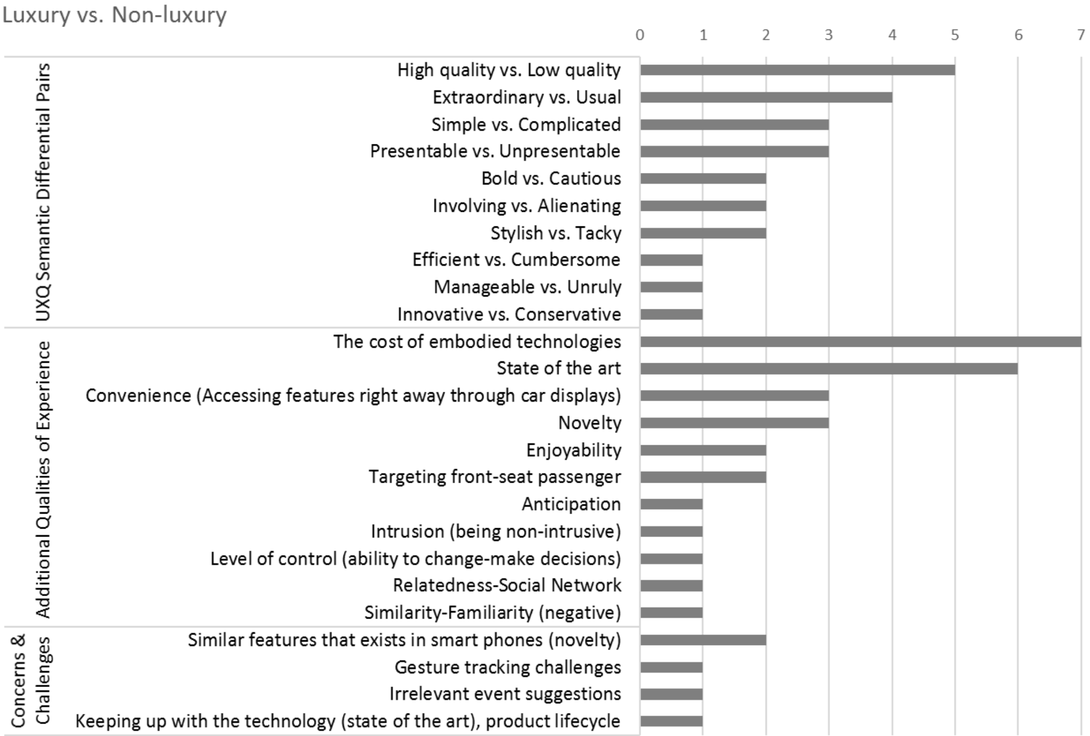


Figure 5.22 Luxury in relation to qualities of experience and related concern and challenges

If we look at the semantic differential pairs in UXQ, among pragmatic qualities, ‘simple vs. complicated’ was found to be the most referred one in relation to luxury. It is also important to remind that simplicity was mentioned by the participants as a pragmatic quality which is more about visual presentation of the information, in comparison to efficiency, manageability or predictability. This points out the significance of simple look/presentation of information in luxury infotainment systems. Besides, being ‘extraordinary vs. usual’, which was mostly associated with new sensory experiences brought by gesture recognition, AR (HUD) and TOLED technologies, was the most highlighted stimulation-related hedonic quality of experience. In terms of identification (hedonic quality), luxury was mostly defined through refinement/high-quality of the system.

As mentioned before, the additional qualities of experience were not totally covered in UXQ but highlighted by the participants to express their expectations from the infotainment system. Unsurprisingly, in relation to luxury, we can observe a strong reference to financial value of the system through the estimated cost of the embodied interaction technologies. The reference to the technology embodiment as part of luxury experience is also revealed in the expectation (and concern) of owning a state-of-the-art infotainment system. Other most luxury-related concepts include convenience, novelty, targeting front-seat passenger (being 'exclusive' to front-seat passenger) and enjoyability. Expectation of novelty was also mentioned in relation to the concern of having similar features in other nomadic devices. Another observation was that there was not a direct reference to gesture tracking challenges as an obstacle to luxury experience. This means that having new sensory experiences through state-of-the art technologies is as important as ensuring usability in luxury infotainment systems.

5.5.3 Expected frequency of use of the infotainment features

This section presents and discusses the results of the content analysis of the participants' responses given to the interview question *"Which infotainment features (from the ones that you are offered) do you see yourself using the most/least?"* The participants were free to list more than one item for the infotainment features they expected to use most frequently (Fig. 5.23) and least frequently (Fig. 5.24).

Accordingly, the infotainment features which the participants would prefer to use most were: media, journey info, camera, notifications and book in ranked order. Media menu was mentioned to be a mostly-used feature, since it would have functioned in the background of other travel activities (P11, P20, P21). The infotainment features which the participants would prefer to the least were: the book, camera, journey info and notifications in ranked order. Book was mentioned to be the least utilized infotainment feature because of 'the possibility of motion sickness' (P8, P9, P17, P18, P22, P25, P27), 'personal reluctances to read from a digital screen' (P1, P3, P10, P12, P15, P21, P25, P26) and 'the isolation of the passenger from the driver' (reading as an 'anti-social' activity) (P24).

Notifications were different from the other infotainment features in the sense that they are provided to the front-seat passengers automatically. This might have affected the participants' responses. They might not have mentioned notifications when they were asked to name the features that they would utilize the most, since the users had no control over when and how frequently the system sent notifications in the design proposal and in VR simulation. The participants (4/27) who included notifications (without specifying them as the event suggestions or arrival notification) in their responses justified their selection as they *would have* wanted them to appear frequently since they found them useful and captivating.

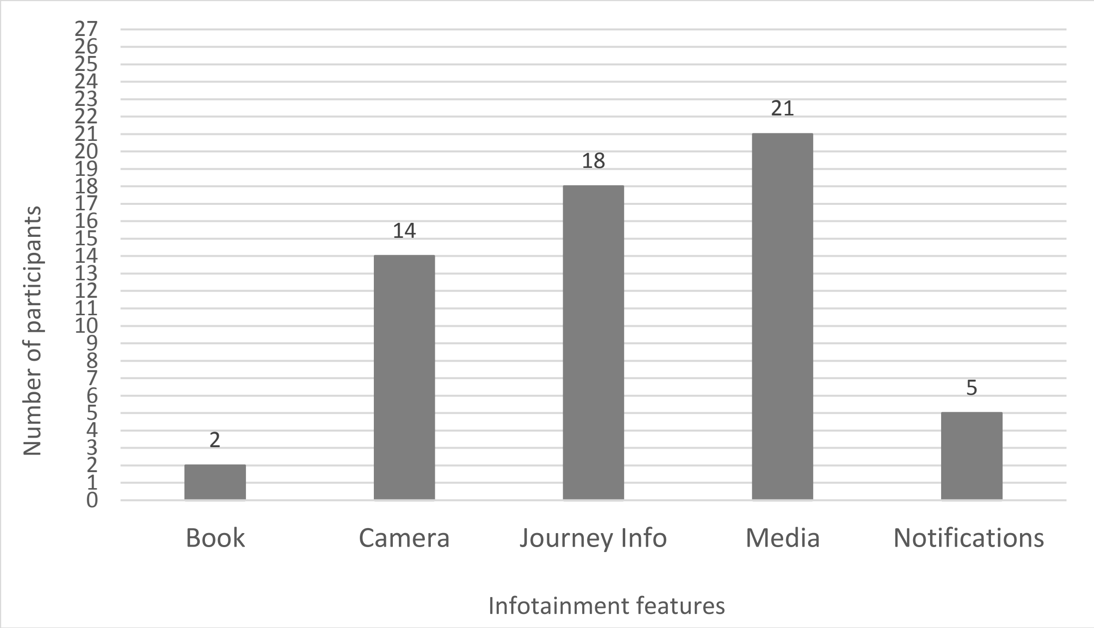


Figure 5.23 Infotainment features with the highest expected frequency of use

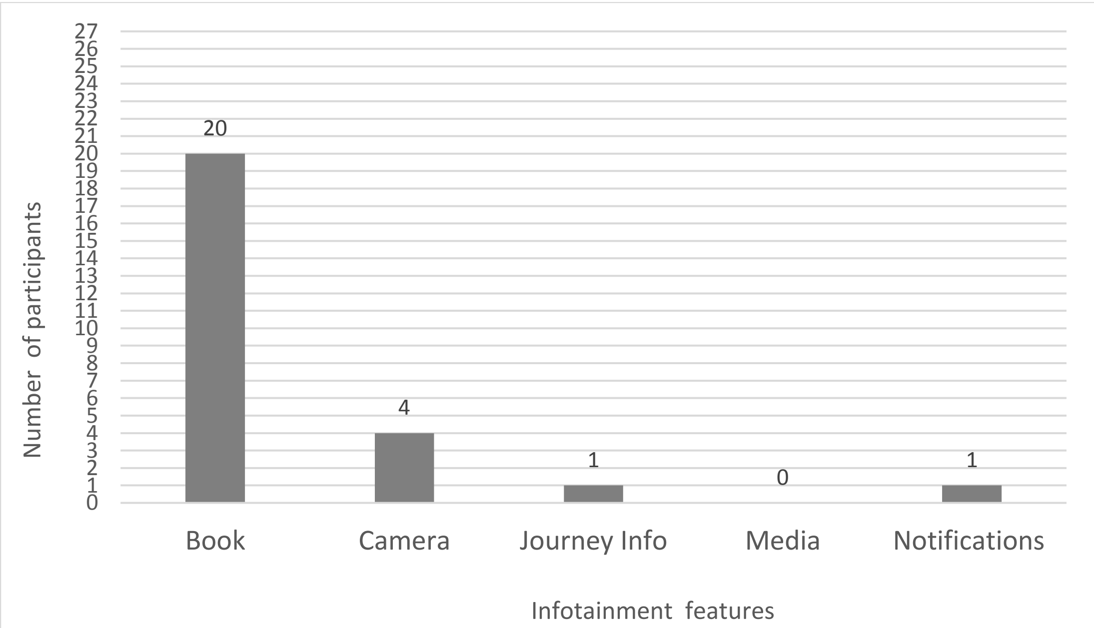


Figure 5.24 Infotainment features with the lowest expected frequency of use

5.5.4 Analysis of the Participants' Suggestions for Future Front-Seat Passenger Infotainment Systems

In semi-structured interviews conducted after VR demonstrations, the participants were encouraged to share their suggestions to improve or enrich the infotainment system. The design proposal they interacted within VR simulation created a reference for discussion to understand their expectations from the future front-seat passenger infotainment systems.

This section presents the analysis of the suggestions under two sections: i) Infotainment Features (Functionalities) & Content, and ii) Aesthetics of Interaction.

As an observation, there were more suggestions about what the infotainment system enables the users to do or what content it provides them than the suggestions regarding aesthetics of interaction. Therefore, suggestions for infotainment features and the content were presented with categories that identify varied directions to upgrade the infotainment system in the *what* level. Both sections include the qualities of experience and the concerns & challenges that the suggestions were associated with. Therefore, by discussing which qualities of experience are expected to be delivered with each suggestion, the system can be enriched by using alternative means (*what* and *how* levels of interaction) for the identified ends (qualities of experience, *why* level) to avoid underexplored technology-driven infotainment solutions.

5.5.4.1 Infotainment features (functionalities) and content

This analysis of the participants' suggestions with regards to infotainment features and content revealed several categories that identify different approaches to improve or enrich the infotainment system in *what* level. These categories include:

- additional infotainment features and content
- expanding the capabilities of the infotainment features that are available in design
- alternative uses of the infotainment features that are available in design
- customisation of the infotainment features and the content
- connectivity
- context awareness

All suggestions made by the participants regarding the functionalities can be associated with the functional value or pragmatic quality from usefulness perspective, since they all aim at making the infotainment features more useful. However, while the participants made suggestions for the provision of improving functionalities, they also had other motivations (e.g. addition of a communication feature to add social value or to improve identification). These will be discussed in relevant sub-sections.

a. Additional infotainment features and content

This category presents the functionalities and the content that research participants would like to add to the available infotainment features in VR prototype. Related suggestions are clustered and listed under information, communication and entertainment sub-categories (See Table 5.5).

Table 5.5 Additional infotainment features and content as suggested by the participants

	Additional infotainment features and content: Additions to the information, entertainment and communication features and content

Other possible information features and content:
• **Information about the performance of the car**
  ○ Car performance (fuel usage-velocity) (2/27)
• **Information about the driver**
  ○ Driver's performance review (1/27)
  ○ Driver's wellbeing info (1/27)
• **Information about the surroundings**
  ○ Areas of interest based on the media-TV (1/27)
  ○ Interesting facts about the region-area (1/27)
  ○ Nearby facilities
    ▪ Eating (7/27)
    ▪ Petrol station (5/27)
    ▪ Toilet (1/27)
  ○ Parking places (3/27)
  ○ Shows-cultural events (theatre etc.) (3/27)
  ○ Opening hours of the nearby shops (1/27)
  ○ Tourist attractions (1/27)
• **Information about the Journey**
  ○ Traffic-Road Conditions-Alternative Routes (6/27)
  ○ Navigation directions from HUD for co-piloting (1/27)
• News (5/27)
• First aid tips for emergency (1/27)
	Other possible communication features and content:
	• Live streaming from the camera (4/27)
	• Messenger (4/27)
	• Phone calls (4/27)
	• Skype Video calls (4/27)
	• E-mail access & notifications (3/27)
	
	Other possible entertainment features and content:
	
	• Videos-Movies (8/27)
	• Audio-book (1/27)
	• Games (11/27)
	• Live TV (1/27)

'Additions' to communication features and content can be mostly explained with the participants' motivation for ***relatedness to social network,*** whereas additions to entertainment features increase the variety of options for a ***stimulating*** experience. ***Being informative*** had been identified as an expected quality of experience, which was anticipated to be delivered with the items in the category of 'Other possible information features and content' (See Table 5.5). Other expected qualities of experience that underly the suggestions for information features can be listed as follows:

- ***'anticipating' users' information need*** (e.g. petrol station information when the fuel level is low);
- ***involvement in journey*** (e.g. info about surroundings);
- ***facilitating collaboration / involvement in social interactions with other car occupants*** (e.g. navigation directions from HUD for co-piloting, parking places)

- ***ensuring safety and security*** (e.g. first-aid tips, driver's performance review, driver's wellbeing info).
- ***avoiding motion sickness*** (e.g. audio-book)

Information about the driver's performance and wellbeing (P7, P26) and first aid tips for emergency (P21) are the two functionalities which had not been identified in the literature review of passenger-oriented automotive UX studies and the technology review of the concept cars.

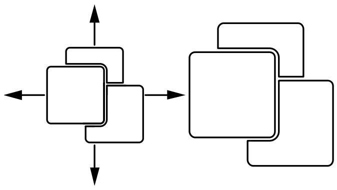
b. Expanding the capabilities of the infotainment features that are available in design

This category presents the ways of expanding the capabilities of the infotainment features that were already present in the VR simulation. This expansion was discussed to be achieved either through addition of sub-functionalities or enrichment of the content provided in related menus. Table 5.6 can be referred to see the list of suggestions per each feature.

There were various concerns and motivations behind the addition of sub-functionalities or enrichment of available content. They included:

- ***facilitating collaboration*** (e.g. parking info/guide, entrance of the event venue in arrival notification, event suggestions with the information that the driver needs)
- **avoiding** ***division of attention between HUD & the travel context*** / ***enabling involvement in journey*** (e.g. to have quick readings in book menu)
- ***ability to make changes as expected from an 'innovative' and 'presentable' and 'high-quality' infotainment system*** (e.g. camera view from different points, maps access-search function in journey info, zooming into & exploring & changing the route)
- ***'anticipating' the need 'to record memories' (evocation)*** (e.g. photos automatically taken by the car in specific locations), or just ***enabling the passenger to capture specific memories*** (e.g. taking snapshots of the video footage)
- ***facilitating involvement in / relatedness to social network*** (e.g. live-streaming from the camera, event suggestions with attendees' information)
- ***facilitating involvement in journey*** (e.g. media based on the surroundings)
- ***facilitating involvement in use of system / being non-intrusive*** (providing follow-up suggestions, enabling passenger to place an order in event-venue suggestions)

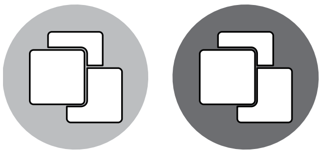
Table 5.6 Expanding the capabilities of the available infotainment features

	**Expanding the capabilities of the infotainment features that are available in design** Improvement of the infotainment features in the design proposal through addition of sub-functionalities or enrichment of the content provided in related menus
Arrival notification: • Parking info /guide (1/27) • Entrance of the event venue (1/27) **Book:** • Decreasing the time spent on the menu-quick readings (1/27) **Camera:** • Taking video (7/27) • Camera view from different points • Adjusting the size and position of the camera frame (4/27) • Preview in camera (3/27) • Selfie camera (2/27) • Photos automatically taken by the car in specific locations (2/27) • 360-degree camera view (1/27) • Live streaming from the camera ((1/27) • Taking snapshots of the video footage (1/27) **Event suggestions:** • Setting preferences for event suggestions (customisation) (5/27) • Ability to place an order (2/27) • Providing follow-up suggestions (1/27) • Event suggestions with attendees' information (1/27) • Event suggestions with information that the driver needs (1/27) • Purchasing tickets to the suggested events (1/27)	**Greeting:** • Animation with a photo instead of the logo (customisation) (1/27) **Journey info:** • Maps access in journey info (4/27) • Zooming into & Exploring & Changing the route (2/27) • Communication of traffic in journey info line (1/27) • Indicating the location of the car (with colour, a car icon etc.) (1/27) • Points of interest section in Journey Info (1/27) • Search function in journey info (1/27) **Media:** • Media based on the surroundings (context awareness) (2/27)

c. Alternative uses of the infotainment features that are available in design

In VR simulation the infotainment features were experienced by the participants within a predefined travel scenario and order. This category was set to compile the suggested functionalities that offered alternative uses of the available infotainment features for different use cases-contexts which were not included in the VR simulation (See Table 5.7). The suggestions included using the camera to record accidents either by utilizing it like a dashcam for continuous record of the windscreen view (P3, P11, P20) or through instant footages when the front-seat passenger notices something going wrong on the road (P13, P17, P18). Another alternative use of the camera feature was discussed as recording the route and later referring to this footage as part of the navigation (P18). The same participant also suggested sharing this footage with others, so that they could have followed the same route to a specific destination. The discussions in the follow-up interview also involved using the car infotainment features as part of popular apps (It requires connectivity, which constitutes another category in this section.) It means that the data created through the infotainment features can be utilized as part of connected applications, which was mentioned by P27 as using the infotainment system "as an extension of what I already have". For example, if the user has access to the Instagram app through the infotainment system, the application can provide an option of using the camera system of the car to take the picture.

Table 5.7 Alternative uses of the infotainment features that are available in design

	**Alternative uses of the infotainment features that are available in design** Functionalities that offer alternative uses of the available infotainment features
• Camera to record accidents (6/27) • Car infotainment features as part of popular apps (2/27) • Camera to record the route for other and others' journeys (1/27)	

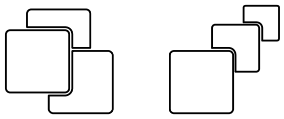
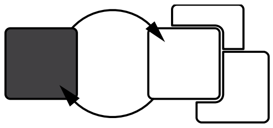
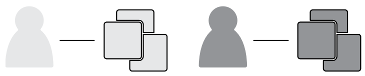
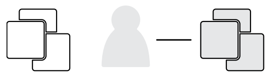
The concerns and motivations behind the alternative usages of the infotainment features include:

- ***ensuring safety and security*** (e.g. camera to record accidents)
- ***convenience*** (e.g. having an easier access to car's camera to record accidents)
- ***collaboration / involvement in social interactions with other car occupants*** (e.g. camera to record the route for other journeys)
- ***collaboration / involvement in social network*** (e.g. camera to record the route to guide others in navigation)
- ***keeping up with technology / owning a 'state of the art' infotainment system*** (e.g. car infotainment features as part of popular apps).

d. Customisation of the infotainment features and the content

The suggestions that were listed in previous categories clearly identified the functionalities or the content that can be added or improved. In addition, some participants also discussed the ways to change the infotainment features and the content based on their personal preferences, yet they did not necessarily identify the features and the content they would like to customise. Participants' suggestions for customisation included the categories of i) setting the favourites (P1, P21), ii) adding and removing infotainment features (P14, P21, P27), iii) log-in system for personalized infotainment (P8, P23), and iv) setting content preferences (P5, P6, P8, P11, P15, P20).

Table 5.8 Customisation of the infotainment features and the content

	Customisation of the infotainment features and the content
	**Setting 'favourites'** The ability to cluster the infotainment features as favourites vs. others (2/27)
	**Adding and removing infotainment features** The ability to change the infotainment features accessed via front-seat passenger infotainment system (3/27)
	**Log-in system** Front-seat passenger identification to have the access to customized infotainment features and content (2/27)
	**Setting content preferences** The ability to customize the content accessed via the infotainment system (6/27)

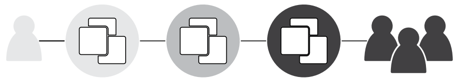
Customisation enables the infotainment system to adapt to changing needs and interests of the users and offer information, entertainment and communication in a sustainable way. The customisation suggestions were justified by the participants with the following expectations/motivations.

- ***avoiding passenger distraction*** (e.g. being able to remove features, setting content preferences for relevant event suggestions)
- ***protection of privacy*** (e.g. log-in system, setting content preferences not to be approached by every event organizer or venue)
- ***owning a 'stylish' infotainment system*** (e.g. being able to add/remove features, setting the favourites)
- ***enabling the system to 'anticipate' users' needs*** (e.g. setting content preferences for event suggestions).

e. Connectivity

Connectivity was one of the most referred features (20 out of 27 participants) regarding the ways to upgrade the infotainment system. Connected infotainment systems enables the users to have access to other products, services and systems, which is also expected to contribute to provision of information, entertainment and communication in a constantly updated, therefore, sustainable way. Table 5.9 presents the list of connectivity-enabled features that front-seat passengers would like to make use of through the infotainment system.

Table 5.9 Connectivity

	**Connectivity** Access to other products, services and systems through connected infotainment system
• Internet connection (11/27) • Access to other apps and subscriptions (9/27) • Social media integration (8/27) • Access to the infotainment features from a phone outside of the car (2/27) • Transfer of preferences data from synchronised accounts or previous activities (2/27) • Car-smart home connectivity (1/27)	

Under connectivity, access to other apps and subscriptions were mentioned by nine participants (9/27) with the motivation of enriching infotainment experience with customised and varied content. The examples given by the participants included: connecting to the media streaming devices/applications like Netflix (P11, P13, P20) and Spotify (P23) in media menu and having access to the Kindle library in the book menu (P11, P23). Another motivation behind the access to smart devices applications was stated as being able to share the content created within an infotainment menu with other people through social media apps. This can be exemplified with holding access to the car's camera as part of the Instagram app offered in the infotainment system and publishing the photo.

Access to car apps from a phone outside the car was another connected infotainment feature mentioned by P9 and P22. One use case can be exemplified by the comments of P9, where connectivity extends the service provided in the car to the outside for another mode of travelling:

> It's just useful especially with the GPS, when you are driving the car, sometimes you can't actually make it to the actual destination. You might need to park somewhere else and still you might need to walk, is it still linked with your phone? When you get out of the car does it change it to a walking mode, so you are still be able to get to your destination.

We cannot discuss connectivity without Internet connection, however, eleven participants referred to internet connection as having internet browsers as well as being connected to internet.

Social media integration was pointed out as a connected infotainment feature as well. The motivation was either to share things with other people (P12, P20, P25) or using the display to check social media feed (e.g. checking notifications through HUD) (P7, P8, P11, P13, P27). Regarding social media, one participant (P7) stated the following:

> If you could take the Twitter or Instagram feed as an option to have on the screen and then sort that by location/direction/travel, so you can see the relevant social media as you travel in the area.

Such social media integration connects the passenger not only to social media but also to the context of travel, which constitutes a clear example for strengthening the connection of the infotainment features with the surroundings. Another use of connectivity mentioned by the participants was transferring the preferences data from synchronised accounts or previous activities to customise the infotainment experience (P9, P27). This was offered as an alternative to set the preferences in the system manually (P9).

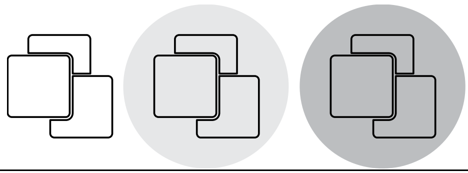
The concerns, challenges and expected qualities of experience that were associated with connected infotainment features can be summarized as:

- ***keeping up with technology/owning a 'state of the art' infotainment system*** (e.g. access to other apps and subscriptions)
- ***avoiding data storage/allowance issues*** (e.g. access to other apps and subscriptions)
- ***relatedness to/involvement in social network*** (e.g. social media integration)
- ***facilitating involvement in journey*** (e.g. social media feed based on location)

f. Context awareness for infotainment features & content

Context awareness was mentioned by the participants either i) to enable passengers to have access to the features/content that were most relevant to travel context (leisure vs. daily commute, P1) or ii) to improve specific features provided in the design proposal. These infotainment features included context-aware event suggestions based on the proximity of the car to the venues (P6) or type of travel (leisure vs. daily commute) (P4), updated journey info that is not only based on the generic distance:speed calculation but also on live traffic data (P6), and media based on surroundings that provides e.g. movie options based on areas of interest (P7, P21).

Table 5.10 Context awareness for infotainment features & content

	**Context awareness for infotainment features & content** Provision of infotainment features and content that are relevant to the context of travel
• Context-aware event suggestions (2/27) • Media based on surroundings (2/27) • Updated journey info (car-infrastructure connectivity) (1/27) • Favourite functionalities based on the context (1/27)	

The underlying concerns, challenges and expected qualities of experience of the context-aware infotainment features / content suggested by the participants can be summarised as follows.

- ***accuracy, not to fail to take infrastructure into account*** (e.g. updated journey info, context-aware event suggestions based on proximity)
- ***avoiding irrelevant event suggestions*** (e.g. context-aware event suggestions based on type of travel)
- ***facilitating involvement in journey*** (e.g. media based on surroundings)
- ***anticipating passenger's needs*** (e.g. favourite functionalities based on the context)

5.5.4.2 Aspects of aesthetics of interaction

This list of suggestions made by the participants regarding the aspects of aesthetics of interaction should not be regarded as a list of revisions that can be immediately implemented to the infotainment system. Therefore, in this section, the responses are clustered under four headings (i.e. action-reaction aspects; presentation; spatio-temporal and kinesthetic aspects; and visual aspects) and their relevance are discussed. The numbers in the parenthesis refer to the number (out of 27) of participants who suggested a revision-improvement in related aspect of aesthetics of interaction.

Additionally, each of the suggestions is presented with the relevant concern(s) and the expected qualities of experience that they are associated with. In other words, within such means-ends relationship, the ends are also identified so that the designers can explore alternative means for a specific end.

a. Action-reaction aspects

Table 5.11 presents the list of suggestions made by the participants regarding the way the user of the infotainment system acts while using the system and the response he/she receives.

Table 5.11 Suggestions for action-reaction related aspects

ACTION-REACTION (12/27)
• Specific gestures defined for frequent-basic actions (6/27) • Adding short-cut functions to button (4/27) • Voice activation (3/27) • Being able to turn on-off the notifications (2/27) • Adding audio feedback (1/27) • Addition of a feedback to notify the user about the notifications (1/27) • Addition of voice recognition for driver to involve in use of the infotainment system (1/27) • Being able to deactivate gesture recognition (1/27)

The concerns, challenges and expected qualities of experience put forward by the participants for action-reaction related aspects involved the following:

- ***avoiding gesture tracking challenges*** (e.g. adding short-cut functions to button, being able to deactivate gesture recognition)
- ***avoiding accidental selections*** (e.g. specific gestures defined for frequent-basic actions)
- ***avoiding fatigue-discomfort*** (e.g. specific gestures defined for frequent-basic actions)
- ***avoiding the possibility to miss the notifications*** (e.g. addition of a feedback to notify the user about the notifications)
- ***avoiding front-seat passenger's distraction*** (e.g. being able to turn on-off the notifications)
- ***avoiding alienation from the driver / facilitating involvement in social interactions with other car occupants*** (e.g. addition of voice recognition for driver to involve in use of the infotainment system)
- ***owning an extraordinary, innovative, and luxury infotainment system*** (e.g. voice activation

As can be seen from the list, most of the action-reaction suggestions aimed to improve usability of the gesture-controlled infotainment system.

b. Presentation

Table 5.12 shows participants' suggestions regarding the way system present information and interaction possibilities. The suggestions were either related with ***clarity in presentation*** (e.g. one word for each menu) or ***avoiding gesture tracking challenges*** (e.g. split screens (HUD and TOLED) for each menu to increase the size of interactive elements).

Table 5.12 Suggestions for presentation

PRESENTATION (2/27)
• One word for each menu (1/27) • Split screens for each menu (to increase the size of interactive elements) (1/27)

c. Spatio-temporal and Kinesthetic Aspects

Table 5.13 shows the suggestions made by the participants about spatio-temporal and kinesthetic aspects. The suggestions regarding the two aspects of interaction are handled together since spatio-temporal aspects offered a direct influence on users' kinesthetic experience. For example, the participants referred to the body postures while suggesting revisions in spatio-temporal aspects of interaction. Furthermore, the participants expressed that the motivation behind a few of their suggestions regarding spatio-temporal aspects is to avoid fatigue and physical discomfort; which also underlines the connection between the spatio-temporal and kinesthetic aspects.

Table 5.13 Suggestions for spatio-temporal and kinesthetic aspects

SPATIO-TEMPORAL and KINESTHETIC (17/27)
• Bigger-wider interactive elements to add margin of error in gestural controls (6/27) • Access to TOLED features via HUD (to increase the size of interactive elements) (5/27) • Common (easy to point-reach) location for basic menu buttons (3/27) • Decreasing the frequency of notifications through customisation of the notifications (3/27) • Access to HUD features on TOLED (2/27) (customisation) • Customisation of the duration of pointing (activation time) (2/27) • Access to notifications in a sequential way (1/27) • Adjusting the position of the images on HUD (based on passenger's sitting posture) (1/27) • Decreasing the time spent on the menu-quick readings (1/27) • Increasing the number of interaction steps (to increase the size of interactive elements) (1/27)

The concerns, challenges and expected qualities of experience put forward by the participants for spatio-temporal and kinesthetic aspects involved the following:

- ***efficiency-manageability-simplicity, avoiding gesture tracking challenges*** (e.g. common (easy to point-reach) location for basic menu buttons on GUI, bigger-wider interactive elements to add margin of error in gestural controls, customization of the duration of pointing (activation time), increasing the number of interaction steps to increase the size of interactive elements, access to TOLED features on HUD to increase the size of interactive elements)
- ***ensuring readability/visibility*** (e.g. adjusting the position of the images on HUD based on passenger's sitting posture, increasing the number of interaction steps to increase the size of interactive elements)

- ***avoiding division of attention between HUD and travel context*** (e.g. decreasing the time spent on the menu with quick readings)
- ***avoiding fatigue-discomfort*** *that results from not changing the body posture for a duration of time* (e.g. access to HUD features on TOLED / access to TOLED features via HUD to change reading posture)
- ***avoiding front-seat passenger's distraction*** (e.g. access to notifications in a sequential way, decreasing the frequency of notifications through customization of the notifications)
- ***avoiding driver's distraction / ensuring safety and security*** (e.g. common (easy to point-reach) location for basic menu buttons
- ***owning a 'high-quality' system*** (e.g. access to TOLED features via HUD to be less constrained by the size of TOLED).

d. Visual aspects

Table 5.14 shows the suggestions made by the participants about how the infotainment system looks.

Table 5.14 Suggestions for visual aspects

VISUAL (9/27)
• Visual customisation (5/27) - Customisation of the overall look (colours, lay-out, 'skins') - Customisation of the font size and other graphic elements - Customisation of the greeting animation (photo instead of logo) • Decreasing the size of notifications (2/27) • Increasing the transparency of HUD (2/27) • Being able to turn on-off the visibility of the TOLED screen (1/27) • Changing dashboard material to increase the contrast between the figures and background on TOLED (1/27) • Increasing the depth effect on TOLED (1) • Automatic screen brightness adjustment (1/27)

The concerns, challenges and expected qualities of experience put forward by the participants for visual aspects involved the following:

- ***ensuring readability/visibility, being inclusive*** (e.g. changing dashboard material to increase the contrast between the figures and background on TOLED, automatic screen brightness adjustment, customisation of the font size and other graphic elements)
- ***owning a 'stylish' infotainment system*** (e.g. changing dashboard material to increase the contrast between the figures and background on TOLED)

- ***to avoid driver's distraction*** (e.g. being able to turn on-off the visibility of the TOLED screen
- ***facilitating collaboration / not preventing the passenger from co-piloting*** (e.g. decreasing the size of notifications, increasing the transparency of HUD)
- ***avoiding intrusion, facilitating involvement in journey*** *(as expected from luxury systems)* (e.g. decreasing the size of notifications, increasing the transparency of HUD to minimize the occlusion of the road)
- ***owning* a 'presentable' *infotainment system*** (e.g. automatic screen brightness adjustment, customization of the font size and other graphic elements)
- ***owning a 'high quality' infotainment system*** (e.g. increasing the depth effect on TOLED)
- ***owning a* 'luxury' *infotainment system*** (e.g. increasing the transparency of HUD).

5.5.5 A Framework to Conceptualize Front-Seat Passenger's Changing Roles and Relations with the Infotainment System

One of the main observations about the participants' appraisals and suggestions regarding the infotainment system is that their relationship with their surroundings, the other car occupants, and the infotainment system keeps changing. Sometimes, the participants would like to watch a movie from the media menu, which would isolate them from their surroundings and the other car occupants for a period. Within their own private bubble, the participants would like to enjoy this media feature on a bigger display, (i.e. HUD), instead of TOLED on the dashboard. However, sometimes they would like to concentrate on what is going on the road and complain about the size and limited transparency of the HUD and how it prevents them from co-piloting. The participants' changing expectations from the way they interact with the infotainment system and the functionalities offered by the system depend on how the relations among the infotainment system, the car occupants and the surroundings are built during their journeys.

To tackle the complexity of the participants' changing expectations during the journey, this section presents a framework that visualizes the relations among the main actors and components of the infotainment experience and discusses what the infotainment system can offer to strengthen or weaken these relations (to switch from one mode to another).

Figure 5.25 demonstrates the main actors and components involved in the front-seat passenger's infotainment experience. In the centre there is the front-seat passenger, who keeps interacting with the infotainment system, the driver and other car occupants, and the surroundings (including the car interior) placed on three corners. The lines among these actors and components present the relations among them. In the following sections, normal lines represent that there is / should be a strong relation among these actors and components, dashed lines refer to the situations when they are / should be isolated from each other.

It is important to remind that the infotainment system is designed and prototyped within the context of Bentley Continental GT, a coupe type of automobile that generally hosts only two front-seat occupants: the driver and the front-seat passenger. During the interviews, a few participants, especially the ones travelling with their families during their daily life, referred to their interactions with other car occupants as well. Therefore, the framework will mainly focus on the driver as the main companion of the front-seat passenger, but it will also include the examples from interactions among the front-seat and rear-seat passengers.

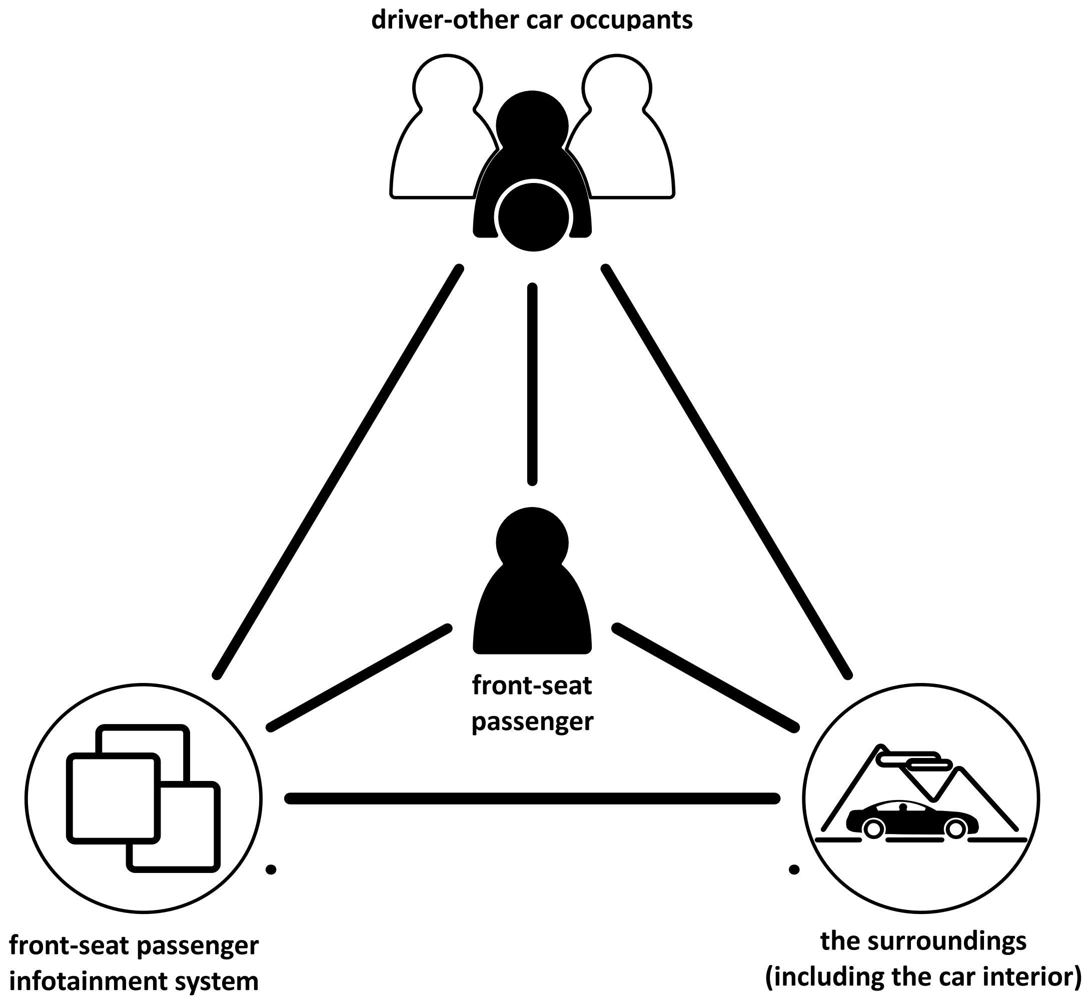


Figure 5.25 The main actors and components of the front-seat passenger infotainment system experience

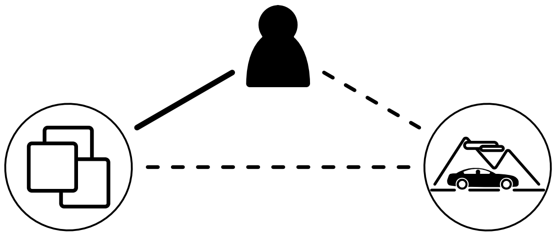
Figure 5.25 illustrates the two main actors / components that are involved in the front-seat passenger's interactions with the infotainment system: the driver (and other car occupants), and the surroundings. Therefore, the discussions in this section will be presented in two strands: i) Relations among front-seat passenger – infotainment system – surroundings, and ii) front-seat passenger – infotainment system – driver (and the other car occupants).

5.5.5.1 Relations among front-seat passenger – infotainment system – surroundings

The analysis of the interviews shows that the focus of the front-seat passenger may shift from the infotainment system to the surroundings and *vice versa.* There are also times where the infotainment system should integrate the surroundings/surroundings information, so that the front-seat passenger can interact with the both simultaneously. In addition, there may be also situations when the front-seat passenger's interactions with the infotainment system should be turned off. These diverse situations/modes are further explained in Table 5.15. It also presents the aspects of aesthetics of interaction and functionalities that are provided in design / suggested by participants to be provided in future designs, so the system can adapt to the changing relations among front-seat passenger – infotainment system – surroundings.

Table 5.15 Relations among Front-Seat Passenger – Infotainment System – Surroundings

Front-Seat Passenger - Infotainment System



Isolation of the front-seat passenger infotainment system from the travel context or surroundings, so passengers can immerse themselves in infotainment features provided in the car and create their own bubble.

Aesthetics of Interaction

Visual:

- Decreased transparency of HUD while reading book (not to be distracted by what is happening on the road)
- Decreasing the size of HUD notifications (when user is dealing with another infotainment feature)

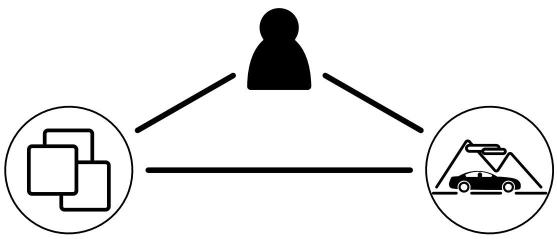
Spatio-temporal:

- Making HUD notifications step-wise rather than providing them as pop-ups (when user is dealing with another infotainment feature)

Functionalities (Infotainment Features) & Content

- Setting preferences for event suggestions (to receive only the relevant notifications, to decrease their frequency)
- Being able to turn off the notifications (when user is dealing with another infotainment feature)
- Games, movies, live TV (immersive entertainment activities)

Infotainment System – Surroundings



Integration of the surroundings to the infotainment system when passengers would like to both enjoy / be aware about the surroundings (including the car interior and the surroundings info) and utilize the infotainment features.

Aesthetics of Interaction

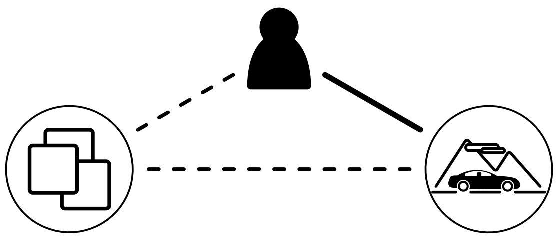
Visual:

- Use of augmented reality / HUD (Digital images overlaid on the surroundings)
- TOLED to enjoy luxury veneer material at the background of the infotainment menus.
- Decreased size or increased transparency of HUD to keep eye on the road

Functionalities (Infotainment Features) & Content

- Camera, any suggestion under ‘camera’ (Table 5.6)
- Book menu with short readings
- Journey info, any suggestion under ‘information about surroundings’ (Table 5.5)
- Destination-song match, indication of the remaining time to the destination via number of songs, media (e.g. movies) based on surroundings
- Event suggestions, adding follow-up suggestions (e.g. other venues that are worth-visiting nearby the event venue)
- Providing audio-book feature as well (Less reliance on the visual modality to enjoy the view and the book simultaneously)
- Social media (Instagram, Twitter) feed based on the location/destination

Front-Seat Passenger – Surroundings



Designing the front-seat passenger infotainment system in a way that passengers can enjoy or concentrate on only their surroundings when they wish to do so

Aesthetics of Interaction

Visual:

- TOLED to enjoy luxury veneer material of the passenger dashboard when the system is switched off
- Decreasing the size of HUD notifications

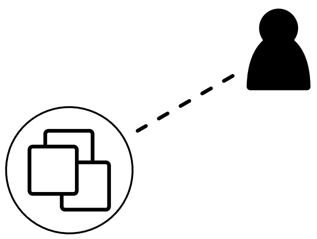
Spatio-temporal:

- Making HUD notifications step-wise rather than providing them as pop-ups
- Decreasing the time spent on the book menu with short readings

Functionalities (Infotainment Features) & Content

- Providing audio-book feature as well (Less reliance on the visual modality to enjoy the view more)
- Setting preferences for event suggestions (to receive only the relevant notifications, to decrease their frequency)
- Being able to turn off the notifications

Situations when the infotainment interactions should/can be turned off



Disabling the front-seat passenger from interacting with the infotainment system. The motivations can include preventing the driver from being distracted or avoiding accidental gestural interaction while engaged in other in-car activities (e.g. eating food, doing make up) that requires the use of hands.

Aesthetics of Interaction and Functionalities (Infotainment Features) & Content

- Temporary deactivation of gesture controls
- Not allowing passenger to watch video-movie through TOLED unless the system is connected to a headphone

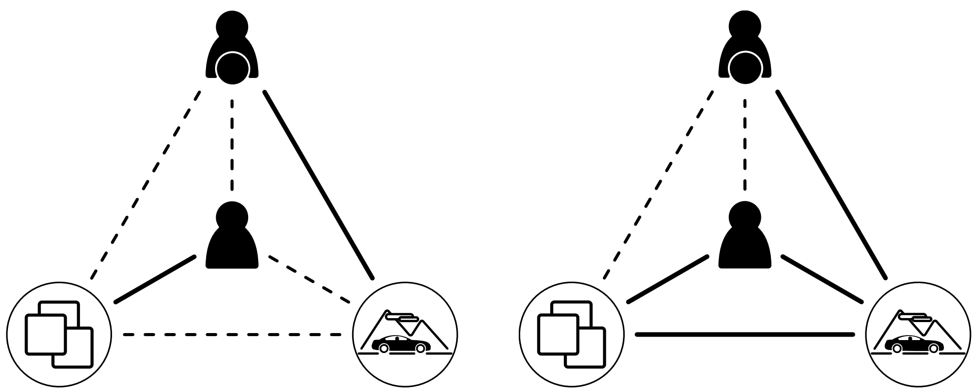
5.5.5.2 Relations among front-seat passenger - infotainment system - driver (and the other car occupants)

This section presents different levels and ways for the driver's (and the other car occupants') involvement in the use of the front-seat passenger infotainment system, including:

- minimum distraction of the driver by the front-seat passenger infotainment system (which is also applicable to the front-seat passenger's wish to only concentrate on the infotainment features)
- indirect involvement of the driver in the use of the front-seat passenger infotainment system
- direct involvement of the driver in the use of the front-seat passenger infotainment system
- isolation of all car occupants from the use of front-seat passenger infotainment system

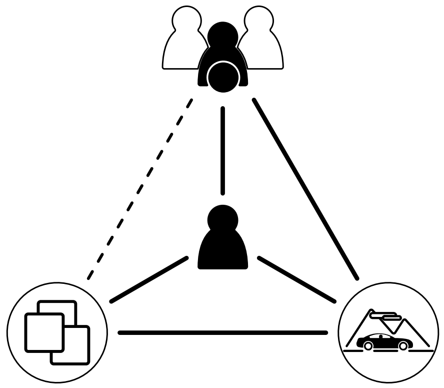
Table 5.16 demonstrates in what situations driver may/may not be involved in the use of the front-seat passenger's infotainment system. It presents the aspects of aesthetics of interaction and functionalities that are provided in design / suggested by participants or to be provided in future designs to facilitate these situations.

Table 5.16 Relations among Front-Seat Passenger - Infotainment System - Driver (and other car occupants)

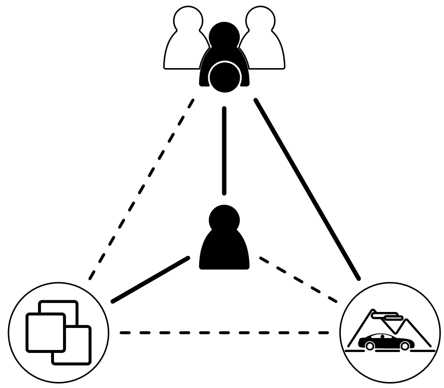
Minimum distraction of the driver by the front-seat passenger infotainment system

Designing the infotainment system in a way that it creates minimum distraction for the driver when he/she needs to fully concentrate on the driving task.
Aesthetics of Interaction Visual: ▪ Being able to turn on/off the visibility of the displays from driver's point of view, ▪ Avoiding audio-feedback, providing headphones, Spatio-temporal: ▪ Common (easy to point-reach) location for basic menu buttons: keeping the movement range of the pointing gestures in minimum

Indirect/temporary involvement of the driver in use of the front-seat passenger infotainment system

A



B



Designing the infotainment system in a way that it facilitates the communication among the car occupants during the driver's indirect/temporary involvement in the use of the front-seat passenger infotainment system:

The driver does not directly interact with the front-seat passenger infotainment system but communicate with the front-seat passenger for the infotainment tasks that are performed by the passenger. The relevant activities/situations may involve interactions with the surroundings / surroundings info (A) or other infotainment features (B). These activities/situations are exemplified by participants as:

- Co-piloting (A)
- Review of the event suggestions together (A)
- Taking pictures (of the scenery that the driver wants to capture) (A)
- Selection of the media (entertainment options) together (B)

Aesthetics of Interaction

For all activities/situations:

Visual aspects:

- Being able to turn on/off the visibility of the displays from driver's point of view

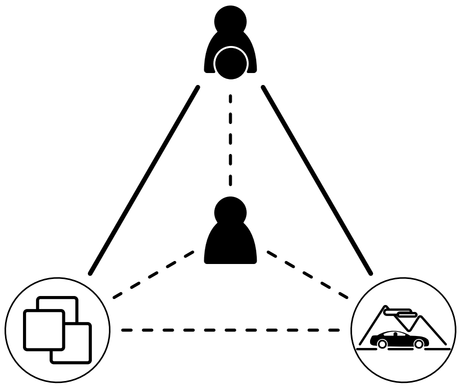
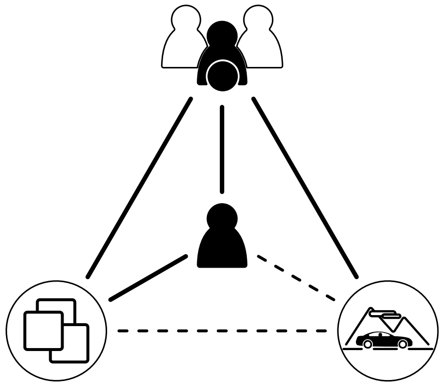
Functionalities (Infotainment Features) & Content

For all activities/situations:

- Being able to exchange information among the driver's and front-seat passenger's displays

For co-piloting and review of the event suggestions together:

- See Table 5.3: all items listed under 'information about surroundings' (e.g. places) and 'information about journey' (e.g. navigation directions from HUD)
- See Table 5.4: all items listed under 'arrival notification' (e.g. parking info), 'journey info' (e.g. maps access) and 'event suggestions' (e.g. event suggestions with the information that driver needs)
- Camera to record the route for other journeys (to be used as part of navigation)

Direct involvement of the driver in use of the front-seat passenger infotainment system	
A 	**B** 

Designing the infotainment system in a way that driver can also directly interact with the front-seat passenger infotainment system when necessary. The motivations may involve:

A. Prevention of driver's distraction by disabling the front-seat passenger from the use of the infotainment system (e.g. young front-seat passengers playing with the system).

B. Driver's involvement in social in-car entertainment

Aesthetics of Interaction

Action-reaction & Sensory aspects:

- Voice control by the driver (B)

Functionalities (Infotainment Features)

To prevent driver's distraction (A):

- Giving driver the ability to turn off the system, taking control of the system in a way that the front-seat passenger cannot control it until driver allows him/her to do so.

To facilitate driver's involvement in social in-car entertainment (B):

- Games (e.g. quizzes) with voice control
- Audio-books to be listened by all car occupants

5.6 Discussion

This section presents a discussion of the results of the evaluation of the user experience of the front-seat passenger infotainment system. The main aim of this discussion is to present how findings of the user study can inform UX designers and design researchers in future (luxury) front-seat passenger- oriented infotainment design projects. Therefore, the section will go through each strand of the analysis by highlighting the key findings and presenting the key design considerations in bullet points.

5.6.1 Key Design Considerations regarding 'Qualities of Pleasant User Experience and The Front-Seat Passenger Infotainment System Aspects'

Section 5.5.2 quantitatively demonstrated and discussed the key the front-seat passenger infotainment system aspects that were associated by the participants with diverse qualities of pleasant user experience, which were also connected with the luxury values.

For example, the pragmatic quality-related (functional value) semantic differential pairs (e.g. simple-complicated) were mostly related with the sensory aspects of interaction that played role in manipulation of the system: gestures and the related spatio-temporal aspects (e.g. boundary of movement set by the size of the buttons, duration of pointing required for menu activation).

On the other hand, the most generalizable deduction from stimulation-related appraisals would be the appreciation of new sensory experiences. Therefore, the visual aspects of the system started to play more role in delivery of stimulation by using both HUD and TOLED displays. These displays combined the physical and the digital either through AR or transparency that did not hinder the interior material while presenting information. Gestures were one of the most mentioned interaction aspects (this time as part of positive appraisals), since it brought about a new sensory experience in manipulation.

With regards to identification (symbolic-social value), 'involvement' (alienating vs. involving) was mostly associated with visual, spatio-temporal and action-reaction aspects of the notifications or the functionalities. 'Refinement' (high quality vs. low quality) appraisals were more related with the gestures and the related spatio-temporal aspects as in usability appraisals. It showed that usability was a prerequisite quality for a refined experience; however, it didn't affect the appraisals of other hedonic qualities to the same extent. Appraisals regarding how stylish and presentable the infotainment system was mostly defined through visual aspects with a specific reference to the visual consistency of the infotainment system with the luxury car interior.

So, how can designers of the future front-seat passenger infotainment systems benefit from this analysis? They can pay more attention to the infotainment system aspects that played more significant role in the delivery of each quality of pleasant user experience if they are to integrate interaction technologies in a way that the system will offer similar interaction aesthetics and functionalities to the ones in the infotainment system proposal. This section will now present additional key points that the UX designers of the front-seat passenger infotainment systems should take into consideration for each quality of pleasant UX measured in the UX questionnaire.

5.6.1.1 Delivery of pragmatic quality through the front-seat passenger infotainment system

- **Finding the balance: Simple & predictable GUI vs. manageable gestural controls**
  Pragmatic quality-functional value of the front-seat passenger infotainment system was interpreted either as the easy comprehension of how to manipulate the system or easy manipulation (executing the infotainment tasks with ease). The results show that the participants had no significant issues with understanding how to control the GUI with gestures. This was explained in the interview with the interaction aspects like clear visual communication of functionalities with menu icons, or familiarity of the lay-out / spatial arrangement of the interactive elements. The ratings towards being simple and predictable can also be explained with the limited variety of hand gestures, as controlling the system by pointing at it and diversifying the manipulations only through other spatio-temporal aspects (e.g. direction and duration of pointing) did not require recalling specific hand gestures for specific interaction tasks. On the other hand, what lowered the pragmatic quality / functional value of the infotainment system were the challenges that participants experienced in the execution of the gestural controls. These challenges were mostly explained with the interaction aspects like 'limited boundary of the movement set by the size/width of buttons/slider, and the position of the interactive elements (home button at the far corner). Therefore, it can be claimed that the visual aspects of GUI also constitute affordances for the kinesthetic experience of the system. What is familiar, predictable and simple to understand within GUI (e.g. the home/back button which was expected to be at the top corner) can be unruly or cumbersome regarding the execution of gestural controls (e.g. pointing at the far corner to turn back to home). Similarly, the lack of specific gestures for specific manipulations contributed to the simplicity of the infotainment system, but it had negative effects in execution of a few interaction tasks. It was observed that especially the manipulations that required fine tuning, such as sliding the book page or changing the volume, were challenging with pointing gestures due to the limited range of movement defined by the length/width of the sliders. This brings us to the conclusion that cognitive and physical dimensions of the usability should not be considered in isolation from each other in (front-seat passenger) infotainment system designs, since they can be in conflict especially during the execution of gestural controls.

- **Making the experience unpredictable in a positive way: Surprise vs. unpredictability.**

  The participants sometimes referred to the term of unpredictability as 'surprise'. The surprising aspects were mostly related with the way that notifications (e.g. event suggestions) were provided to the front-seat passengers (e.g. AR, pop-up, automatic suggestions), which showed the appreciation of push information. The implications of this observation for the design of the notifications will be mentioned in further detail in the ensuing section.

5.6.1.2 Stimulation through the front-seat passenger infotainment system

- **Investigating the balance between stimulation vs. usability (pragmatic quality)**

  The results of the analysis of the experience prototyping point out that the embodiment of the interaction technologies providing new sensory experiences made the biggest contribution to the front-seat passenger's stimulating experience. For example, controlling the system with gestures was appreciated as being innovative, extraordinary and bold despite the usability challenges it brought about.

  A similar conflict between stimulation and usability was observed in other infotainment aspects. For example, while familiarity of the system and limited variety or number of the functionalities (and related content) were appreciated as being simple, efficient and manageable, the very same aspects were used to justify why the infotainment system did not feel innovative, extraordinary, bold or captivating enough. Therefore, UX designers of the (front-seat passenger) infotainment system should handle usability and stimulation together by considering the above-mentioned conflicts between the two.

- **Notifications as a means of stimulation or spam**

  The notifications (e.g. event suggestions) and the way that they were presented automatically through the HUD as pop-up menus were found stimulating, since they constantly kept the front-seat passenger informed about the journey and the surroundings. However, there were also concerns about the possibility of getting distracted by the notifications if they were involved in co-piloting, used another infotainment feature or just enjoyed the scenery.

  The suggestions presented in Section 5.5.4 also showed that depending on how the action-reaction (automatic suggestions), spatio-temporal (frequency of HUD notifications, pop-ups) and the visual (use of augmented reality, size of HUD notifications) aspects are designed, the notifications can be regarded either as a spam that alienates the front-seat passenger from other car occupants / journey / the infotainment system or as a means of stimulation that keeps passenger informed during the journey. In this regard, such automatic suggestions should be considered for infotainment system design to keep the stimulation and the surprise effect live as well as to enable the effective and convenient access to journey-related information. However, the users should have the control over the content, frequency and the visual aspects (size and transparency of HUD) of the notifications; or these parameters should be adjusted through connected and context-aware infotainment systems (e.g. not suggesting new venues on a daily commute to work, petrol station information when the fuel is low).

5.6.1.3 Identification through the front-seat passenger infotainment system

- **Considering diverse approaches to involvement**

  The participants' comments on the ratings for the 'alienating vs. involving' semantic differential pair showed that the involvement of front-seat passenger can be experienced as involvement in communication with other car occupants, in the use of infotainment system (which can be handled under 'stimulation') and in the journey. As discussed in Section 5.5.5, the design decisions that would keep the front-seat passenger engaged in use of the infotainment system (e.g. immersive entertainment features like book or movies) may be alienating for the other car occupants. Therefore, to facilitate the diverse modes of involvement, the front-seat passenger infotainment system design should enable to switch from one mode to another easily or provide solutions that, for example, keep the passenger both engaged in the journey and immersed in the infotainment system (e.g. use of AR in displays, camera feature, entertainment options based on surroundings info).

- **Usability as a prerequisite for refined/high quality infotainment experience**

  It is observed that the infotainment system aspects associated with weak usability (being complicated, cumbersome, unruly, unpredictable) were the same aspects that were used to justify why the infotainment system felt unrefined or low quality. These aspects were mostly related with the gesture tracking challenges and the spatio-temporal aspects (e.g. boundary of movement set by the size/width of the buttons/sliders) that play a role in the way gestural controls were executed.

5.6.2 Additional Qualities of Experience

- **Alternating semantic differential pairs: Identification of alternative keywords or concepts for the existing categories that define qualities of a pleasant infotainment UX**

  The semantic differential pairs in the UX evaluation questionnaire enabled the assessment of the participants' infotainment experience in terms of manipulation (usability), stimulation and identification. These qualities of experience relate to functional value, experiential value and symbolic value of luxury. The analysis of the follow-up interview presented a list of alternative concepts/keywords that can enable UX designers to elaborate on manipulation (usability), stimulation and identification (Please check Table 5.1) regarding the (front-seat passenger) infotainment systems.

- **Expectations beyond manipulation, stimulation and identification**
  There were also keywords or concepts that could not be classified under manipulation (usability), stimulation and identification. However, they are proposed to useful in specifying the additional expectations from the luxury front-seat passenger infotainment system for UX designers' reference. They include:

  - **capturing moments/memories**: With regards to the role of memories in user experience, 'evocation' is presented as another hedonic quality in the literature (Hassenzahl, 2003), yet it is not included in AttrakDiff questionnaire (revised for the present study's UX evaluation questionnaire). Hassenzahl (2010) argues that 'evocation' is not applicable for the first-time evaluation of a product, as the term is related with the memories of past experiences. However, in this study, 'capturing moments-memories' refers to the system's ability to *create* and *capture* memories through camera-like infotainment features. Therefore, this concept can constitute a relevant criterion for a pleasant user experience of an infotainment system.

  - **safety, security**: Safety-Security was found to be another concern/quality of experience underlined by the participants, especially regarding the possibility of driver's distraction, which constitutes a generalizable concern for all front-seat passenger oriented automotive HMI solutions especially in non-autonomous car concepts.

- **the cost of embodied technologies:** There is not enough discussion on the effects of financial value in user experience in UX literature. The results of this study show us that the participants' guesses about the financial value of the infotainment system (their estimation of the possible cost of the embodied interaction technologies) played a big role in defining the system as a luxury one. Therefore, the designers of luxury automotive HMI should carefully attend to the selection of the most state-of-the-art interaction technologies that will also add financial value to the system.

The participants' additional expectations from the front-seat passenger infotainment system were revealed through their concerns and the challenges, including:

- **prevention of fatigue, physical discomfort**: Fatigue/physical discomfort emerged as a concern because of the physical effort needed while interacting with the infotainment system. For example, keeping the hand steady for menu activation or keeping the head up/down for a period due to the fixed position of the displays were mentioned to be the likely reasons of physical discomfort and fatigue. Prevention of fatigue and physical discomfort should be considered as one of the criteria in defining parameters for the spatio-temporal aspects of the (front-seat passenger) infotainment systems, especially for the ones that integrate gesture recognition.

- **prevention of motion sickness, nausea:** Motion sickness and nausea were highlighted especially with regards to the book feature. Participants had concerns that reading for a long period of time in a moving car would make them nauseous. It constitutes another design problem for UX designers to explore, as automotive HMI integrates more functionalities that require constant attention to a screen which also incorporates reading texts.

- **protection of privacy:** Privacy was considered in different levels: concerns about the privacy of each passenger (e.g. if the info on passenger display is visible to driver, log-in system), privacy of all car occupants (e.g. being approached by every venue for event suggestions), and protection of privacy of others (e.g. taking pictures of others while they are not aware of it). Protection of privacy applies to any automotive HMI application that is supposed to be used in presence with the other car occupants and that provides connectivity to the infrastructure.

5.6.3 Key Design Considerations regarding 'Luxury and the Front-Seat Passenger Infotainment System'

- **The qualities of experience that are most related with the manifestation of luxury**

The analysis of the user study also involved the specification of the mostly referred i) experience qualities (the semantic differential pairs in UXQ), ii) additional qualities of experience (see Section 5.5.2.4), and iii) the participants' concerns and challenges to describe luxury vs. non-luxury experience. The top qualities and concerns that were associated with luxury point out a balanced distribution between the pragmatic and the hedonic ones. Besides, as would be expected from all luxury products, the financial value that is defined by the estimated cost of the interaction technologies, seems to be the top indicator of the luxury infotainment system according to the participants. Therefore, the luxury front-seat passenger infotainment system should be:

  - of high financial value
  - state-of-the-art
  - high quality
  - extraordinary
  - presentable
  - convenient
  - simple

These shortlisted qualities can be referred when UX designers and design researchers need to specify the expectations from the luxury interactive systems.

- **The luxury content as the luxury 'materials' of the infotainment system**

  Concerning the infotainment system aspects, in addition to the use of state-of-the-art technologies providing extraordinary sensory experiences to front-seat passengers, use of any content/material that is already associated with the luxury brands and lifestyle was also appreciated by the participants as luxury for the infotainment experience. Examples include greeting animation with sparkling Bentley logo, information about the luxury destinations (e.g. image of the desert menu at the Connaught Hotel) and the transparent OLED celebrating the hand-crafted wooden veneer of the passenger dashboard. Therefore, the communication of luxury in 'digital' interactive systems, especially the automotive HMI that integrates gestural controls instead of the physical ones; the strategy to use 'luxury materials' (e.g. use of aluminium instead of plastic controls) can be replaced with the strategy of using digital content with luxury symbolic value and designing the system in consistence with the luxury car interior.

5.6.4 Key Design Considerations regarding 'Participants' Suggestions for Improvement and Enrichment of The Front-Seat Passenger Infotainment System'

- **The means-ends relationship within the *why*, *what* and *how* levels of front-seat passenger infotainment system interactions**

  Earlier on in Section 5.5.4, the participants' suggestions for the future front-seat passenger infotainment systems and their reasoning for *why* they made these suggestions were presented. This is to help UX designers to understand the means-ends relationship within a front-seat infotainment system by handling the means as the functionalities and the content (*what*) and aesthetics of the interaction (*how*) and by handling the ends as the motivations identified for each suggestion category (*why*).

  The main motivations behind participants' suggestions for improving and enriching the functionalities and the content can be compiled as:

  - Involvement in social interactions with the other car occupants (collaboration), involvement in the journeys and involvement in the use of the system
  - Keeping up with the technology / owning a state-of-the-art infotainment system (e.g. car infotainment features as part of popular apps)
  - Owning an infotainment system that can anticipate user needs (e.g. favourite functionalities based on the context, taking photo automatically at specific locations)

  Compared to the main motivations behind the participants' suggestions for improving and enriching the functionalities, aesthetics of interaction-related suggestions have more pragmatic motivations as the term 'pragmatist aesthetics' (Petersen et al., 2004) suggests. These motivations include:

    - Avoiding gesture tracking challenges
    - Avoiding passenger distraction
    - Ensuring readability and visibility

- **Enriched infotainment does not always mean more infotainment features.**

  The suggestions regarding the functionalities demonstrated that the participants would like to use the infotainment system in the fullest sense through addition of new functionalities and content, expansion of the capabilities of the features provided in design or reconceptualization of the available infotainment features in new use cases. Increasing the variety of features enhances the possibility of the infotainment system's appeal to different front-seat passengers; however, this would make the infotainment system less manageable. Therefore, there is a need to filter the enriched infotainment features and content to keep them relevant to the user and the context. This is where customisation, connectivity and context awareness are expected to contribute to the infotainment experience. As the categories regarding functionality-related suggestions show, designers of the (front-seat passenger) infotainment systems should consider not only

  - what functionalities (infotainment features) and content can be provided to the passengers, but also
  - how the system and/or the user manages these functionalities and the content (e.g. customisation: setting preferences), especially when there is strong reference in participants' suggestions to an evolving system that keeps up with the technology and anticipates the user needs.

5.6.5 Key Design Considerations regarding 'The Framework to Conceptualize the Front-Seat Passenger's Changing Roles and Relations with The Infotainment System'

- **Ensuring the adaptability of functionalities, content and the aspects of interaction to front-seat passengers' changing relations with the main actors and components of the infotainment system**

  The participants' suggestions pointed out conflicting motivations, as they relied on how the relations among the infotainment system, the car occupants and the surroundings have been built during the journey. To tackle the complexity of the participants' changing expectations, this research presented a framework that visualizes these relations. The analysis then demonstrated a variety of modes, in which the front-seat passenger may prioritise the relation with one actor/component of the infotainment experience over the other. Each mode was presented with the aspects of interaction and the functionalities that would serve best for the related situation.

In this regard, what the infotainment system should do is to enable the front-seat passenger to switch from one mode to another, therefore, make the functionalities, content and the aspects of interaction adaptable to these modes.

- One of the promising solutions can be customisation. Examples include enabling the passenger to turn on/off displays and controls, adjust the size and transparency of displays/interactive elements, access the infotainment features from any display/any part of the displays, and adjust the frequency of notifications through setting preferences for the event suggestions.
- However, switching among these modes may need to be executed quickly and manual adjustments for each mode may not be convenient for the passenger. This is where the anticipation of the passenger needs plays a role. The system should be context-aware to be able to handle some infotainment tasks automatically. The examples include photos automatically taken by the car in specific locations, not suggesting venues/events on a daily commute to work, automatic screen brightness adjustment and providing notifications in a more stepwise way when another infotainment feature is on.
- Connectivity is also significant for the same reason. Through the exchange of the user preference data some of the customisation can be handled automatically.

CHAPTER 6.

CONCLUSIONS

6.1 Introduction

This chapter presents the summary of the phases of the PhD research, the answers given to the research questions, the contributions of the research to knowledge, and the limitations and implications of the research. It also includes specific sections that synthesize the answers given to the research questions by providing concise recommendations for luxury front-seat passenger infotainment system design and VR prototyping of the car HMI. It concludes with directions and opportunities for future research.

6.2 The Summary of the Phases of the PhD Research

6.2.1 Literature Review of Dimensions of User Experience and User-Product Interactions

The main aim of the PhD research was set as 'to investigate the experience dimensions of luxury infotainment systems that will empower the front-seat passengers through experience prototyping with VR simulation'. Therefore, one research question that needed to be answered in the research was 'RQ1.How can the qualities of luxury user experience be manifested via different aspects of front-seat passenger infotainment systems?'. The first step in answering this question was conducting a literature review on dimensions of user experience and user-product interactions. It was crucial to know 'what *metrics* define a pleasant user experience' (RQ2) as well as 'how user interactions with the infotainment system can be deconstructed into separate elements' (RQ4).

The dimensions of user experience and user-product interactions were presented with reference to Hassenzahl's framework of *why, what* and *how* levels of interacting with technology (2010). Accordingly, the *why* level was deconstructed as qualities of a pleasant user experience with the synthesis of pragmatic-hedonic qualities of UX (Hassenzahl, 2003), human needs (Sheldon et.al., 2001), and pleasures (Jordan, 2000). The *what* level was deconstructed as functionalities & content. The *how* level was deconstructed as the aspects of aesthetics of interaction. The synthesis of the aesthetics of interaction literature (see Figure 2.5) possessed two main categories: i) the aspects that are specific to a sensory modality (e.g. visual, audio, tactile and kinesthetic aspects) and ii) the interactivity aspects that are not specific to a sense (e.g. spatio-temporal, action-reaction and presentation aspects, adapted from Lenz et al., 2014).

The deconstruction of the interactive system and the user experience enabled the discussion of what specific aspect of the front-seat passenger system contributes to what specific quality of the pleasant user experience. The contribution of this phase to the PhD research will be detailed later in Section 6.3. (as answers to questions RQ2 and RQ4).

6.2.2 Literature Review of the Concept of Luxury and Luxury Values

To answer 'RQ2. What metrics define a pleasant user experience; how does the concept of luxury relate to these metrics?' the review of the 'luxury studies' in marketing literature was relied on to identify the values that are expected to be delivered via luxury products/systems/services. These luxury values were identified as: financial value (the price value of a luxury product), functional value (the technical and functional superiority of a luxury product), symbolic value (the identity of the luxury product/brand and its socially constructed meaning, social value), and experiential value (value derived from an individual's experience of a luxury product/service).

A discussion on the luxury values in relation to the qualities of experience (pragmatic-hedonics qualities of UX, human needs, pleasure) was also offered. Please refer to Table 2.4 to view the corresponding terminology. The contribution of this phase to the PhD research will be detailed later in Section 6.3. (as an answer to questions RQ2).

6.2.3 Literature Review of Contemporary Automotive Infotainment Solutions to Empower Front-Seat Passengers

As a first step to answer the 'RQ5. How can interaction technologies be used to deliver (new) infotainment functionalities and interactions to empower front-seat passengers?', the literature review analysed both academic and industrial efforts that investigated the empowerment of the front-seat passengers through automotive user interfaces. The main source for the academic studies was the automotive UX literature, whereas industrial efforts were demonstrated through the technology review of a selection of the concept cars presented in several automotive/technology shows held in 2015-2016. The analysis revealed the diverse approaches followed in empowering the front-seat passengers with reference to the *why, what* and *how* levels of infotainment interactions. It presented new control and display configurations, interaction technologies, trends followed in application of these technologies (*how*) as well as a list of new functionalities (infotainment features, *what*) that were envisioned for the future infotainment systems. It also gathered the concepts that identify the expected hedonic and/or pragmatic qualities from passenger infotainment systems, such as 'reduced boredom' or 'sense of involvement' (*why*). The key findings included:

- **Solutions towards more sensorially enriched automotive HMI that are expanded beyond the driver dashboard (to whole car interior):** Please see Figure 2.16 for the analysis of the trends in in-car interactions.

- **Need to develop front-seat passenger infotainment systems that go further than selective duplication of driver-oriented solutions** (e.g. Lack of flexible solutions like portable displays, repetition of driver-oriented functionalities in infotainment displays on the passenger dashboard)

- **Lack of investigation of the expected contributions of the new interactions and functionalities to UX:** The solutions demonstrated the application of the most recent interaction technologies and functionalities, but the motivations behind these front-seat passenger-oriented solutions were not always clear. In other words, there were a variety of means for undefined ends.

6.2.4 Literature Review of Experience Prototyping with VR Simulation

This part of the literature review elaborated the concepts and practices regarding experience/interaction prototyping and the use of VR in prototyping. It presented the dimensions to consider 'things to communicate' (e.g. filtering dimensions: *what to prototype*) and 'ways to communicate' (e.g. manifestation dimensions: *fidelity, scope* and *medium)* to form a prototype (Lim et al., 2008). The review continued with introduction of VR by mentioning its position within the 'reality-virtuality continuum' (levels of mixed reality: AR, VR) and its key aspects (e.g. immersion, presence). VR and AR simulation technologies were also identified to be referred while determining the medium of the experience prototype. It finally presented the use of VR-AR in design research (including the automotive HMI appraisals) and discussed the advantages (e.g. safety) and disadvantages (e.g. simulator sickness) of using simulation in user studies. The key findings include the following:

- **Utilization of the interactive product aspects to structure prototyping decisions:** If we refer to Hassenzahl's framework of *why, what* and *how* levels of interacting with technology (2010) again, the experience prototyping of an interactive system can be re-defined as communication of the *how* and *what* levels and to investigate their relationship with the *why* level. This phase of the research showed that whilst deciding 'what to prototype' within the infotainment system; the aspects of aesthetics of interaction (*how*), the functionalities & the content (*what*) and the context can be used as a new list of 'filtering dimensions'.

- **Additional assessment requirements that are brought by using simulation in user studies:** The review of the academic studies which discuss the key aspects of VR and the advantages/disadvantages of using simulation in user studies showed that experience prototyping with VR requires an evaluation of how being in a virtual environment affects users (e.g. simulation sickness).

- **Underexplored potentials of VR in automotive HMI appraisals:** It was observed that there was a lack of adequate number of studies on the use of VR as a means of UX research that goes beyond usability evaluations. Regarding the use of VR in automotive sector; the most-mentioned examples include vehicle design and development, assembly training and driving simulators. Although there were also academic studies on the use of VR in automotive HMI appraisals; the interactions with these systems were handled as driver's secondary tasks affecting driving performance. In other words, the focus was on the manipulation of the car rather than the interactions with the HMI.

6.2.5 Focus Group: Exploration of Simulation Challenges of Interaction Technologies (with the VEC)

The focus group study was conducted with the four staff members of the VEC which as a research partner involved in the simulation development. The aim of the study was to shortlist the interaction technologies presented in the concept cars review to be applied to the infotainment system design (See Figure 4.1). The technologies to be discussed in the focus group were selected based on their potentials and limitations (e.g. elimination of the audio feedback because of the risk of driver's distraction). To facilitate the discussion, the author generated initial ideas for the front-seat passenger infotainment system. These ideas were presented as illustrations to show possible applications of the technology to the front-seat passenger's area. The discussion included potential challenges to communicate interaction aesthetics offered by each technology with VR and the potential simulation technologies to prototype each interaction technology. Then, the technologies were put in order based on i) the simulation effort needed, ii) availability of simulation technologies and expertise at VEC, as well as iii) their range of application in industry (See Figures 4.7, 4.8, 4.9). Therefore, the scope of the interaction technologies (to be applied to design) was limited based on what the VEC can deliver through its simulation facilities and expertise.

Key findings of the focus group study are as follows:

- **Aspects of interaction aesthetics as the main determinants of the simulation challenges and prototyping medium:** The results of the study revealed that it was not possible to find a match between the interaction technologies and the simulation medium in a straightforward way. Simulation challenges may differ depending on the way the interaction technology is embodied in infotainment system design, which alters the interaction aspects that need to be communicated/tracked/modified. For example, the tactile and kinaesthetic aspects of interaction (e.g. texture, weight) may need to be prototyped when TOLED is used as a portable display rather than as a fixed display.

- **Compensation of incapabilities of VR with addition of haptic controls & displays, interactive physical prototypes and physical props:** The study showed that the addition of haptic controls & displays, interactive physical prototypes and physical props to virtual environment could facilitate prototyping of specific interaction technologies that offer tactile and kinesthetic interactions. Haptic controls and displays (e.g. touchpads) were suggested as a prototyping solution for the technologies e.g. touch recognition and surface haptics. Interactive physical prototypes were mentioned when there is a shape changing haptic feedback (e.g. alive geometry). Physical props (with optical tracking markers) are mentioned as a prototyping solution where a portable/malleable/graspable physical item is used as a means of control and display (e.g. flexible-portable transparent OLED, tangible user interfaces).

- **Levels of similarity between interaction technology and simulation technologies:** Another conclusion drawn from the focus group was that if the aim is high-fidelity communication of the interaction aesthetics, the simulation technology and the interaction technology that will be prototyped may need to be the same or very similar in working principle. The examples include eye-gaze recognition, surface haptics as well as gesture recognition.

6.2.6 Concept Development of the Front-Seat Passenger Infotainment System

In this phase of the research the author created digital illustrations of a travel scenario with a series of functionalities (infotainment features) (See Figures 4.11 and 4.12) for the front-seat passenger infotainment system. The ideation also included design proposals for the control and display alternatives that were based on the interaction technologies shortlisted in the focus group study (see Figures 4.13 and 4.14). The alternatives were then discussed with the Bentley Motors HMI design team regarding their suitability to Bentley Continental GT experience. Please see Section 4.3.2.3 to review the key points in discussion.

6.2.7 Design Detailing and Simulation Development

As a conclusion of the discussions with both research partners (the VEC and Bentley Motors), a combination of head-up display and a fixed display (transparent OLED) on the passenger dashboard was selected as the display (information provision) solutions for the final design proposal. Pointing gestures were defined as the main means of controlling front-seat passenger infotainment system. The system also included a ready-at-hand physical button with a touch sensitive surface on the passenger door armrest, which was used for activation-deactivation of the system as well as volume adjustment. The infotainment features / tasks in the design proposal (to be experienced through VR simulation) consisted of system activation, photo taking (with the camera), journey information viewing, book reading, event suggestion, playing music in media, ‘approaching’ notification, arrival notification, and system deactivation. Please refer to Section 4.4.1 to review the details of the front-seat passenger infotainment system design.

The simulation development phase of the research utilized the interactive product aspects (the *how* and *what* aspects) to structure prototyping decisions: the main medium of the experience prototype of the infotainment system was decided to be a VR-HMD (HTC VIVE) to enable immersive and interactive demonstration of the infotainment system. The gesture-tracking was achieved by the LeapMotion hand tracker, which was mounted in front of the VR-HMD. The decisions regarding the fidelity and scope of the prototype were individually identified for each aspect of aesthetics of interaction, functionalities (and relevant content) and the context.

The simulation development process included two main tasks: visualisation and programming which were completed in parallel to each other and as iterative processes. (Please refer to Table 4.16 to view sub-tasks and contributions from the VEC staff to each sub-task). In this study, programming was also utilized as a means of design detailing. The parameters for interaction aesthetics (e.g. setting the duration of pointing to activate a menu) were set and tried out repetitively together with the software engineer at the VEC. Trying out the programmed infotainment interactions enabled the author to notice the minor usability and simulation medium-related issues that were not foreseen. The solution to these issues required revisions in the GUI design, which had implications on the GUI layout, the button sizes, and the font type and sizes.

6.2.8 Experience Prototyping of the Front-Seat Passenger Infotainment System through VR Simulation

Experience prototyping of the infotainment system was conducted as individual sessions with 27 participants in total at the VEC Daresbury Labs. Through VR simulation the participants were demonstrated what it might have been like to interact with the front-seat passenger infotainment system within the car. During the approximately 10-minutes VR demo, the participants were introduced several infotainment features (e.g. media menu) within a travel scenario and asked to perform simple interaction tasks (e.g. selection of a menu item, scrolling through a list) as a front-seat passenger. Please see Table 5.1 to review the details of the steps.

The study included several steps and methods of data collection. The evaluation of the user experience included filling in a UX evaluation questionnaire, which was an adapted version of AttrakDiff questionnaire. It included 7-point Likert scale with semantic differential pairs to evaluate the pragmatic quality, stimulation (hedonic quality), identification (hedonic quality) as well as luxury (with an additional semantic differential pair). It was followed by a semi-structured interview where participants were asked to justify their ratings referring to the different aspects of the infotainment system (investigating the link among the *why, what* and *how* levels of the interaction) and mention their concerns about and expectations from the front-seat passenger infotainment system. The evaluation of the VR simulation included filling in the simulation sickness questionnaire before/after the VR demonstration and the presence questionnaire after VR demonstration.

The analysis of the user study involved the statistical analysis of the answers to the questionnaires and the content analysis of the interview transcripts.

Regarding the results of the SSQ, the comparison between the mean scores for the severity of each simulation sickness symptom before/after VR demo showed that the VR simulation did not cause any issue that affected participants' wellness (See Appendix 15). In addition, the results of the presence questionnaire demonstrated that the all realism-related questions measuring i) naturalness of the interactions in VE, ii) sense of involvement in VE, iii) consistency with real world experiences, and iv) sense of navigating around inside VE were rated above 5 in 7-point Likert scale (See exact mean scores with their SD in Appendix 16). These scores point out that the participants' VR experience were more towards realistic and enabled them to imagine themselves using the infotainment system in a real car.

The analysis of the UX evaluation questionnaire also showed that the infotainment system was rated towards the positive end of the Likert scale for every semantic differential pairs.

The results of the content analysis of the follow-up questionnaire will be discussed further in relation to research questions in Section 6.3. However, the main strands of the analysis can be summarised as:

- the quantitative representation of the infotainment system aspects that are the most/least associated with a specific quality of experience, a list of additional qualities of experience (which is a compilation of concepts/keywords that participants utilized while discussing their infotainment system experiences); a list of concerns and challenges; and the quantitative representation of the semantic differential pairs, additional qualities of experience, concerns and challenges that are most associated with being luxury
- expected frequency of use of the infotainment features
- analysis of the participants' suggestions for future front-seat passenger infotainment systems based on the *why, what* and *how* levels of experience
- presentation of a framework to conceptualize front-seat passenger's changing roles and relations with the infotainment system
- discussion of the key points to be considered in design and development of the future front-seat passenger infotainment systems

6.3 Revisiting the Research Questions

This section will provide direct answers to research questions.

RQ1: How can the qualities of luxury user experience be manifested via different aspects of front-seat passenger infotainment systems?

The answer to the RQ1 was given with the analysis of the experience prototyping study; because, it was the phase of the PhD research which enabled the investigation of the link among the *why, what* and *how* levels of the luxury infotainment system interactions with the participation of the users. The following strands of the experience prototyping analysis all focus on the investigation of this link:

- **The link between qualities of luxury user experience and the aspects of infotainment system:** In the follow-up interview, the participants were asked to explain which aspect of the infotainment system affected their ratings in UX evaluation questionnaire. The analysis of this interview quantitatively demonstrated which specific aspect of the infotainment system (among functionalities, interaction aesthetics, context) played the most significant role in delivery of a specific quality of user experience. Section 6.4 and Tables 6.1-6.4 can be seen for the compilation of the most mentioned infotainment system aspects in relation to manipulation, stimulation, identification and more specifically to luxury. These are the aspects that need to be considered while designing luxury front-seat passenger infotainment systems that would integrate similar interaction aesthetics / technologies and functionalities.

  UX Designers need to pay attention to the fact that a solution that targets one quality of experience might affect the delivery of another quality negatively. These conflicts were discussed in Chapter 5 as simple & predictable GUI vs. manageable gestural controls, stimulation vs. usability (pragmatic quality), and different approaches to involvement (involvement in the use of the system vs. involvement in social interactions with other car occupants). The discussion also highlighted the thin line between stimulation and spam as well as surprise and unpredictability in infotainment system interactions.

- **Discussion on the participants' suggestions for future front-seat passenger infotainment systems:** This part of the experience prototyping analysis can also be considered as investigation of the link among the *why, what* and *how* levels of the luxury front-seat infotainment system interactions. The research did not only categorize the participants' suggestions for the functionalities and interaction aesthetics of the future infotainment systems (*what* and *how*), but it also presented their concerns and expectations, which played role in these suggestions (*why*). For example, 'photos automatically taken by the car in specific locations' was coded as a functionality suggestion and categorised under 'expanding the capabilities of the infotainment features that are available in design' (the *what* level). In this example, the participants expected the infotainment system to be more perceptive and anticipate their needs (the *why* level). Please see Section 5.5.4 for further details.

  For generalizability of the outcomes, the means (the infotainment system solutions) and ends (the participants' expectations from / concerns about the front-seat passenger infotainment system) were presented separately. Thus, knowing these expectations/concerns and what answered/triggered them in the infotainment system design, the UX designers can manifest luxury user experience in the future front-seat passenger infotainment systems by using different means rather than the ones that are utilized in this research.

  The compilation of design recommendations (including the interpretations of the participants' suggestions and the researcher's further ideation) that target the most mentioned concerns and expectations of the front-seat passengers can be found in Tables 6.1- 6.5 under Section 6.4.

- **The framework to conceptualize front-seat passenger's changing roles and relations with the infotainment system** also constitutes an answer to RQ1; because it investigated *the changes* within the *why, what* and *how* levels of the infotainment system interactions. The framework demonstrated a variety of modes (Please refer to Table 6.6 to view the compilation of these modes) in which the front-seat passenger may prioritize the connection with one actor/component of the infotainment experience (the infotainment system, the driver and the surroundings) over the other. These modes were presented in the framework through i) the relations among the front-seat passenger – infotainment system – surroundings and

ii) the relations among the front-seat passenger – infotainment system – driver (situations that require driver's involvement in / isolation from the use of the infotainment system).

The framework included the aspects of interaction and functionalities (*how* and *what*) that facilitate each mode (*why)* (Please see Tables 5.13 and 5.14). For example, if the mode suggests that front-seat passenger would like to enjoy both the infotainment system and the surroundings, the system can provide audio-book feature. It would require less reliance on the visual modality to enjoy the view and the book simultaneously.

A (luxury) front-seat passenger infotainment system design should be able to facilitate each mode and enable the transition from one mode to another. Possible design approaches were discussed in Chapter 5 as customisation (e.g. adjustable transparency of HUD images), context awareness (e.g. providing notifications in a more stepwise way when another infotainment feature is on), and connectivity (e.g. automatic customisation based on synchronised accounts).

RQ2: What metrics define a pleasant user experience; how does the concept of luxury relate to these metrics?

RQ2 was a supporting question of RQ1. The answer to this question was provided through literature reviews on 'Deconstructing the Why: The Qualities of User Experience' and 'The Concept of Luxury and Luxury Values'.

The pragmatic-hedonic qualities of UX (Hassenzahl, 2003), human needs (Sheldon et.al., 2001) and pleasures (Jordan, 2000) that were mentioned and compared in the literature review can be considered as dimensions to define what a pleasant user experience is. Nevertheless, these dimensions were not fully represented in the data collection tools (e.g. questionnaires) to evaluate UX. The metrics in UX evaluation tools were mainly based on only pragmatic qualities (usability). In this regard, the research made use of a revised version of the AttrakDiff questionnaire (Hassenzahl et al., 2003), as it offered semantic differential pairs that correspond to most of the qualities / human needs / pleasures that were mentioned as part of a pleasant experience, compilation of which can be found in

Table 2.3. This compilation constitutes a direct answer to the "What metrics define a pleasant user experience?" part of the RQ2.

It was observed that luxury values presented in the marketing literature highly corresponds to the qualities of pleasant user experience presented in deconstruction of the why level. Section 2.3.4 "Luxury Values vs. Qualities of Experience" and Table 2.4 provide the direct answer to the "How does the concept of luxury relate to these metrics?" part of the RQ2. Therefore, semantic differential pairs in the AttrakDiff questionnaire were decided to be relevant to qualify and quantify luxury user experience as well.

However, it was kept in mind that the front-seat passengers might have specific expectations from the infotainment system that were not included in the questionnaire as semantic differential pairs. Furthermore, there was still a need to investigate which qualities of pleasant experience (which semantic differential pairs) were more relevant for the infotainment systems of luxury cars. These research gaps were addressed under RQ3.

RQ3: What are the specific qualities of experience that define the front seat passenger's expectations from the infotainment system; why do front-seat passengers appreciate particular aspects of the infotainment system as luxury?

To answer RQ3, the content analysis of the follow-up interview focused on the way participants talk about their infotainment experiences within VR demonstration. For the first part of the RQ3, the analysis revealed additional qualities of experience (keywords-concepts) that define the front seat passenger's expectations from / concerns about the infotainment system (1). For the second part of the RQ3, the analysis also compiled and quantitatively presented the qualities of experience that are most associated with manifestation of luxury in infotainment system (2).

1) Specific qualities of experience that define the front seat passenger's expectations from the infotainment system:

- **Alternating semantic differential pairs: Identification of alternative keywords or concepts for the existing categories that define qualities of pleasant infotainment UX**: Please refer to Table 5.1 and Table 5.2 to see the full list of alternative keywords or concepts that the participants used to define their expectations from and concerns about the infotainment system. These lists present a selection of the already available terminology in the UX literature based on the user's preferences of the most relevant keywords/concepts to define the infotainment experience. These keywords/concepts can be utilized as a checklist to view alternative ways to define a pleasant infotainment experience by not limiting the metrics to semantic differential pairs used in the UX evaluation questionnaire. Therefore, the most-mentioned ones are also included as part of the design recommendations given in Section 6.4 through the Tables 6.1-6.3 under 'extending the why'. The examples include *anticipation of user needs* for pragmatic quality, *greeting the user / being greeted* for stimulation, and *collaboration* for identification. The concerns of participants about the use of the front-seat passenger infotainment system included *failure to take infrastructure info into account* for pragmatic quality, *passenger's distraction* for (negative) stimulation, and *not being able to communicate information (e.g. event suggestions) to driver* for identification.

- **Identification of the additional expectations from the front-seat passenger infotainment system that could not be classified under manipulation (usability), stimulation and identification:** The relevant keywords /concepts that defined the further expectations from the (luxury) infotainment system were '*capturing moments-memories, safety-security, financial value (the cost of embodied technologies).* Having looked at the list of concerns and challenges mentioned by the participants, the examples for the additional expectations from the infotainment system increased with *prevention* o*f fatigue-physical discomfort, prevention of motion sickness-nausea and protection of privacy.*

  These qualities can be considered as alternative metrics or discussion points in design and evaluation of future (luxury) front-seat passenger-oriented infotainment systems. Table 6.5 can be seen for the brief explanations of these additional expectations (or concerns) to be addressed through design.

2) The qualities of experience that are most related with the manifestation of luxury:

Luxury in the infotainment system was mostly defined by the participants with being of *high financial value (estimated cost of the embodied interaction technologies), state-of-the-art, high quality, extraordinary, presentable, convenient* and *simple.*

These are the qualities that can be given more emphasis while handling UX for luxury products/systems/services both in research and design.

RQ4: When the front-seat passenger infotainment system is considered as an interactive system, how can user interactions with the system be deconstructed into separate elements?

RQ4 was also a supporting question of RQ1. The literature review on “Deconstructing the HOW: Aspects of Aesthetics of Interaction’ and ‘Deconstructing the WHAT’ constituted the response to this question. Figure 2.5 constitutes a direct answer to RQ4, which includes all categories that were used to define the diverse aspects of the front-seat passenger infotainment system. These sections of the literature review are believed to contribute to the research in the following ways.

- **Answering the need of a complex vocabulary to deconstruct the aesthetics of infotainment system interactions:** The synthesis of aesthetics of interaction literature included both sensory-specific (e.g. visual) and non-sensory (e.g. spatio-temporal) aspects. Inclusion of the sensory-specific aspects helped to identify some attributes of the front seat passenger infotainment system in an easier way. For example, in VR demonstration the participants liked the look of the wooden veneer of the passenger dashboard through the transparent OLED. In this example, the interaction aesthetics was not related with the way interactive system presented information or gave feedback to the user, but the visual aspect of the display, which was transparency. Therefore, the vocabulary collected through the synthesis of aesthetics of interaction literature enabled/enables us to handle the infotainment system(s) not only as a user interface but also as a part of the car interior.

- **Discussion of the cause-effect relationship among the diverse categories for the aspects of aesthetics of interaction:** It was observed that the relationship among the existing categories (e.g. spatial vs. action-reaction) of aesthetics of interaction was not visually reflected into any model/framework in the literature. As an addition to the academic sources referred in the literature review, the diagram in Figure 2.5 demonstrated that execution of presentation or action-reaction related decisions are based on the design decisions regarding dynamic/static sensory aspects interaction (sensory, spatial, temporal aspects) or *vice versa.*

RQ5: How can interaction technologies be used to deliver (new) infotainment functionalities and interactions to empower the front-seat passengers?

This question was answered both through the methodology of the research (1) and the results of the user study (2).

1) Steps to follow in application of interaction technologies to deliver (new) infotainment functionalities and interactions to empower the front-seat passengers

Methodology-wise, the phases of the 'research through design' established a reference for future UX research and design that deals with application of interaction technologies within infotainment system. It demonstrated the steps that need to be taken in application of interaction technologies to infotainment system, which are:

- Deconstruction of the interactive system to refer to the aspects of the interactive product as 'ingredients' of the front-seat passenger infotainment system
- Analysis the contemporary solutions and trends based on the *why, what* and *how* levels of the infotainment system interactions
- Exploration of the potentials of the interaction technologies for the front-seat passenger infotainment system and elimination of the technologies.
- Concept development as part of a travel scenario with the feedback from the industrial partner
- Use of digital prototyping tool (VR simulation) as a means of design detailing of the interaction aesthetics of the infotainment system in an iterative way

2) Utilization of the results of the experience prototyping in application of interaction technologies to deliver (new) infotainment functionalities and interactions to empower front-seat passengers

The results of the final study also constitute an answer to RQ5. The analysis reflected on the infotainment functionalities and interactions that were designed within the research and listed the important design considerations for future front-seat passenger infotainment system design. Therefore, whilst developing infotainment systems that target front-seat passengers, a designer can (re)define the way interaction technologies are applied based on the following:

- The mostly referred functionalities and interactions based on different qualities of luxury user experience
- Analysis of the ways of improving and enriching the infotainment system interactions and functionalities through analysis of the participants' suggestions
- The framework to conceptualize front-seat passenger's changing roles and relations with the infotainment system
- Specific qualities of experience that define the front seat passenger's expectations from the infotainment system: using them as an alternative list of metrics (criteria, checklist) for pleasant UX
- The qualities of experience that are most related with the manifestation of luxury: using them as a new list of metrics (criteria, checklist) for luxury UX

Please see Section 6.4 (Tables 6.1-6.6) synthesizing the above-mentioned parts of the user study analysis as design recommendations for (luxury) front-seat passenger infotainment systems, which are expected to guide the application of interaction technologies in development of such car-HMI systems.

RQ6: How can simulation technologies be used to explore the front-seat passenger infotainment concepts? What are the specifications of the experience prototyping tool-methodology to appraise the user experience of the front-seat passenger infotainment system?

This research question was elaborated in several phases of the PhD research, including literature review of experience prototyping with VR simulation, focus group: exploration of simulation challenges with the VEC, design detailing and simulation development and experience prototyping of the front-seat passenger infotainment system through VR simulation. The following list compiles the strategies followed in utilization of simulation technologies and the conduct of the experience prototyping study to answer RQ6:

- **Review of simulation technologies**

- **Discussion of the simulation challenges of selected interaction technologies in a Focus Group:**
    - Reference to initial ideas to help participants to imagine the possible interactions
    - Reference to the aspects of aesthetics of interaction to deconstruct the simulation challenges
    - Reference to list of simulation technologies to discuss other alternatives than the ones available at the simulation centre
- **Prototyping Decisions**
    - What to prototype: Making use of 'Aspects of Interactive Product/System' (aspects of interaction, functionalities, content, context) to deconstruct front-seat passenger infotainment system
    - How to prototype: Definition of scope-fidelity-medium of the prototype for each aspect of the infotainment system
- **Simulation Development**

  Programming:
    - Setting parameters for interaction aesthetics (e.g. setting durations, creating animations), using simulation as a means of design detailing
    - Coding the investigator's controls (e.g. change of panorama images with number buttons, activation of notifications with the 'N' button)

  Visualisation – Design Detailing:
    - Making use of variety of visual media (GUI visuals, 3d models, panoramic Google street view images, videos)
    - Making necessary revisions in GUI (e.g. font-size) based on the simulation limitations and trials
    - Picking the most relevant street view images to the functionalities provided in the design for surroundings and the travel scenario (e.g. journey info in highway, camera in historical town)
- **Experience prototyping (User Study)**
    - Introducing the basics of the design solution and the content of the VR demo with reference to the presentation boards and letting the participants try the VR demo before the actual demonstration
    - Applying simulation sickness and presence questionnaire, encouraging the participants to take off the VR headset anytime they feel sick

- Having a document to refer to while narrating the travel scenario, with notes on how to make changes in virtual environment (e.g. change of panorama images with number buttons)
- Making sure that the investigator can view the participants' first-person VR experience during the study to be able to narrate the scenario and make changes in VR environment according to participant's pace of completion of the tasks
- After VR demo: Using presentation boards to help participants refer their infotainment experience in VR simulation

Section 5.2.4 of the thesis can be referred to see all research materials used to appraise the user experience of the front-seat passenger infotainment system.

The results of the presence questionnaire (See Appendix 16) showed that the VR simulation provided enough realism to enable participants to imagine themselves interacting with the infotainment system in the car. Furthermore, while describing their infotainment experiences in the follow-up interview, the participants referred to every infotainment system aspect (e.g. all categories of interaction aspects, functionalities, context) that were decided to be communicated within the VR simulation. For example, VR as an immersive and interactive prototyping tool was very effective in communication of spatio-temporal aspects of the infotainment system interactions. This was concluded by looking at the number of participants (24 out of 27) who referred to these aspects while evaluating the system.

The results and observations justify the above-mentioned strategies followed in utilization of simulation technologies for experience prototyping of the front-seat passenger infotainment system.

Therefore, the use of VR as a means of experience prototyping of interactive systems can be suggested if

- the interactive system to be prototyped involves more embodied and 3D interactions (e.g. infotainment systems with gestures) than screen-based controls (smart phone applications),
- the context of interaction needs to be digitally communicated with its spatial aspects (e.g. automotive HMI as part of the car interior),

- if the design solution wants to be presented in the form of a new experience rather than as part of a prototyping session (Use of VR-HMD enables the full immersion through isolation from the real environment.).

With regards to ‘prototyping decisions’, a more detailed answer to RQ6 that also presents a roadmap for future car HMI appraisals through VR can be found in Section 6.5 (Table 6.7).

6.4 Design Recommendations for (Luxury) Front-Seat Passenger Infotainment Systems

A. Matching the WHY level with the HOW & WHAT of the infotainment system interactions:

This section will provide design recommendations for (luxury) front-seat passenger infotainment systems through the relations among *why, what* and *how* levels of the infotainment interactions. In this research, the delivery of luxury defines the why level of the front-seat passenger infotainment interactions, however it is not possible to discuss/achieve ‘luxury UX’ without referring to the basic expectations from a pleasant front-seat passenger infotainment UX. For example, a car HMI fails to be a luxury system if it is not easy to use or stimulating enough, yet the system cannot be straightforwardly categorized as a luxury system only because it is easy to use or stimulating. Therefore, design recommendations provided in Tables 6.1 - 6.4 will first cover the main qualities of experience (manipulation, stimulation, identification) in order, to be followed by the design recommendations that are more specific to luxury UX.

Each table is dedicated to a specific quality of experience and provides:

- ‘The *how* and *what’:* The aspects of the infotainment system which need to be paid attention by UX designers/researchers to deliver that specific quality to the user.
- ‘Extending the why’: The list of *main* expectations and concerns which were additionally mentioned by the participants in relation to that quality, to be used by UX designers/researchers as alternative criteria/checklist
- Design recommendations that address the main concerns of the front-seat passengers regarding that quality.

As mentioned under RQ3, the research also revealed other concerns and expectations of the front-seat passengers that cannot be directly categorized under manipulation, stimulation, identification or luxury. These concerns and expectations are listed in Table 6.5 with brief explanations regarding how to integrate them into the formulation of the design solutions for (front-seat) passenger-oriented car HMI.

Table 6.1 Design recommendations for 'manipulation'

<table>
<tr><th colspan="2">WHY: Pragmatic Quality – Manipulation (functional value) *</th></tr>
<tr><td>★</td><td>Pay attention to the below aspects of the infotainment system that were most referred in relation to pragmatic quality.</td></tr>
<tr><td>The HOW & WHAT:</td><td>Challenges in execution of gestural controls (e.g. accidental selections, need of high physical effort) that are mostly affected by i) boundary of movement set by the size/width of the GUI elements, ii) duration of pointing (gestures that require keeping the hands steady for a period of time), iii) position of GUI elements, iv) lack of specific gestures for specific manipulations</td></tr>
<tr><td>★</td><td>Use the below as alternative criteria/checklist in design process.</td></tr>
<tr><td rowspan="2">Extending the WHY:</td><td>Main pragmatic qualities that were additionally mentioned in relation to the infotainment system:
Similarity-familiarity, convenience, clarity, anticipation of the front-seat passenger's needs, level of control (ability to change things / make decisions), being inclusive</td></tr>
<tr><td>Main pragmatic concerns that were additionally mentioned in relation to the infotainment system:
Challenges in execution of gestural controls, driver distraction, readability</td></tr>
<tr><td>★</td><td>Consider the design recommendations below to address the main concerns of the front-seat passengers regarding the pragmatic quality of the infotainment system</td></tr>
<tr><td colspan="2">WHY: Facilitation of the execution of gestural controls through GUI-related decisions
HOW & WHAT:
Enabling wider boundary of movement for the 'pointing' gestures by i) using wider GUI elements in lay-out, ii) enlarging the related GUI element during selection for easier activation or iii) the flexible use of multiple displays (e.g. HUD vs. TOLED), enabling the user to switch to the display of which size is less restricted by the physical parts (e.g. dashboard size)
Dealing with the challenges brought by the duration of pointing by i) duration customisation ii) assigning specific gestures for specific manipulations (e.g. advancing GUI elements, going back to the previous menu) or iii) implementation of the technologies like eye-gaze recognition to use the gaze information instead of duration to confirm user's attempt for the activation.
Dealing with the challenges brought by the position of interactive elements by i) compilation of the basic functions repeated in each menu in a common and easy-to-reach place for an efficient manipulation and ii) assigning specific gestures for specific manipulations (e.g. advancing GUI elements, going back to the previous menu)
Temporary de-activation of gestures to prevent accidental selections</td></tr>
<tr><td colspan="2">WHY: Prevention of driver distraction
HOW & WHAT:
Keeping the range of gestures minimum by e.g. compilation of the basic functions repeated in each menu in a common, easy-to-reach place which is preferably not within the driver's peripheral view
Providing the driver and/or passenger control over the distracting stimuli by e.g. being able to turn on/off the visibility of the displays from driver's point of view (e.g. through split view technology), being able to avoid the audio-feedback with headphones integration
Enabling the driver to de-activate the system when needed</td></tr>
</table>

WHY: Readability (Inclusivity through readability) **HOW & WHAT:** • **Enabling reading in different postures** by e.g. adjusting the position of the text and images on HUD/TOLED accordingly • **Context awareness (lighting conditions) to facilitate reading** by e.g. automatic screen brightness adjustment • **Customisation of the size and colours of the text and other graphic content**
* The recommendations are limited with the scope of the interaction technologies applied into the design solution that was appraised in the PhD research.

Table 6.2 Design recommendations for 'stimulation'

WHY: Stimulation (experiential value)	
★	*Pay attention to the below aspects of the infotainment system that were most referred in relation to stimulation.*
The HOW & WHAT:	**Appreciation of new sensory experiences** such as i) elimination of touch in manipulation of the system by using gestures and ii) the use of both HUD and TOLED which combined the physical and the digital either through AR or transparency that did not hinder the interior material while presenting information **Appreciation of new functionalities** including camera, journey info
★	*Use the below as an alternative criteria/checklist in design process.*
Extending the WHY:	**Main stimulation-related qualities that were additionally mentioned in relation to the infotainment system:** Being state-of-the-art, targeting of the front-seat passenger, well spent travel time / keeping the passenger occupied, novelty, enjoyability
	Main stimulation-related concerns that were additionally mentioned in relation to the infotainment system: Passenger distraction, keeping up with the technology in product lifecycle, similarity with the features provided in smart phones and driver HMI
★	*Consider the design recommendations below to address the main concerns of the front-seat passengers regarding the stimulation provided by the infotainment system.*
WHY: Prevention of passenger distraction (Involvement in the use of the system) **HOW & WHAT:** • **Customisation for relevant content & functionalities** by e.g. setting preferences for event suggestions • **Being able to turn on/off the notifications** • **Control over the frequency of the notifications** by e.g. lessening the number of notifications through customisation • **Provision of notifications in a sequential way** to eliminate the risk of 'spam' feeling in pop-ups, to minimize the sudden occlusion of the road (HUD) / display content (other displays) • **Provision of follow-up richness** by e.g. enabling passenger to place an order in event-venue suggestions or providing follow-up suggestions • **Notifications in 'right' size** to minimize the occlusion of the road (HUD) / display content (other displays) • **HUD notifications in 'right' transparency** to minimize the occlusion of the road	
WHY: Keeping up with the technology in product lifecycle, lack of novelty (similarity with the features provided in smart phones and driver HMI) **HOW & WHAT:** • **Connectivity to provide up-to-date content and functionalities during the car's life cycle** such as e.g. enabling a convenient access to other apps and subscriptions through the car's displays, the use of car infotainment features as part of popular apps (e.g. car's 360-degree-camera feature as part of Instagram app)	

Table 6.3 Design recommendations for ‘identification’

<table>
<tr><th colspan="2">WHY: Identification (symbolic and social value)</th></tr>
<tr><td>★</td><td>Pay attention to the below aspects of the infotainment system that were most referred in relation to identification.</td></tr>
<tr><td>The HOW & WHAT:</td><td>Notification interactions (e.g. size, transparency (HUD), frequency, timing) are the main factors influencing involvement in the journey / the social interactions with other car occupants / the use of the infotainment system
Easy manipulation with gestures is a prerequisite for refinement (high quality vs. low quality). See ‘Execution of gestural controls’ in Table 6.1 to review the interaction aspects that affect the manipulation of the system.
Visual consistency of the infotainment system with the car interior (e.g. use of TOLED on dashboard with wooden veneer) is the main factor affecting how stylish and presentable the infotainment system is.</td></tr>
<tr><td>★</td><td>Use the below as an alternative criteria/checklist in design process.</td></tr>
<tr><td rowspan="2">Extending the WHY:</td><td>Main identification-related qualities that were additionally mentioned in relation to the infotainment system: collaboration, relatedness with the social network</td></tr>
<tr><td>Main identification-related concerns that were additionally mentioned in relation to the infotainment system: Irrelevant suggestions, prevention of the front-seat passenger from co-piloting</td></tr>
<tr><td>★</td><td>Consider the design recommendations below to address the main concerns of the front-seat passengers regarding the identification provided by the infotainment system.</td></tr>
<tr><td colspan="2">WHY: Involvement in journey
HOW & WHAT:
• Integration of surroundings information to functionalities such as media / social media feed based on the on the location
• Integration of the surroundings to the information provision such as the use of AR displays (HUD) and TOLED, arranging the size and transparency of HUD content to minimize the occlusion of the road
• Options for the time spent on the infotainment system such as having shorter texts in book menu
• Options for the presentation and timing of notifications such as making HUD notifications step-wise rather than providing them as pop-ups</td></tr>
<tr><td colspan="2">WHY: Collaboration with the driver / Involvement in social interactions with other car occupants
HOW & WHAT:
• Provision of the information needed for co-piloting such as parking info/guide, navigation directions, event suggestions with the information that the driver needs, entrance of the venue in arrival notification, camera to record the route for other journeys
• Enabling the driver to involve in the use of the infotainment system through alternative sensory input/output such as addition of voice recognition, being able to turn on/off the visibility of the displays from driver’s point of view
• Enabling the front-seat passenger to keep an eye-on the road through e.g. arranging the position, size and transparency of HUD content to minimize the occlusion of the road</td></tr>
<tr><td colspan="2">WHY: Relatedness to the social network
HOW & WHAT:
• The functionalities and content that integrate social information event suggestions with attendees’ information, social media integration
• Enabling the front-seat passenger to share content such as live-streaming from the camera, camera to record the route for other journeys
• Access to varied communication options such as audio/video calls, e-mail, messenger</td></tr>
</table>

Table 6.4 Design recommendations for 'luxury'

WHY: Luxury	
★	*Pay attention to the below aspects of the infotainment system that were most referred in relation to luxury.*
The HOW & WHAT:	**Appreciation of new sensory experiences based on the application of the state-of-the art technologies with high financial value** such as i) elimination of touch in manipulation of the system by using gestures and ii) the use of both HUD and TOLED which combined the physical and the digital either through AR or transparency that did not hinder the interior material while presenting information **Appreciation of the aspects of interaction with established symbolic value** such as use of 'luxury' content (luxury venue suggestions, image of a desert menu in a luxury hotel), greeting animation with luxury brand's logo, use of transparent OLED technology to reveal hand-crafted wooden veneer of the passenger dashboard **Visual consistency of the infotainment system with the car interior**
★	*Use the below as an alternative criteria/checklist in design process.*
Extending the WHY:	**Main qualities that were mentioned in relation to the 'luxury' infotainment system:** being of high financial value, state-of-the-art, extraordinary, presentable, convenient, simple
★	*Consider the design recommendations below to address the expectations from a 'luxury' front-seat passenger infotainment system.*
• **Experiences with updated interactions, content and functionalities:** Offering new interactions that are less bounded with the interaction technologies but the digital content and capabilities through infotainment customisation and connectivity (to keep the system state-of-the-art after purchase / during usage) • **The luxury content as the luxury 'materials' of the infotainment system:** Use of relevant content to the luxury user network and lifestyle (e.g. brunch event suggestions with the image of a desert menu in a luxury hotel) • **Subtle integration of the state-of-the-art technologies to luxury car interior** such as the use of TOLED on luxury wooden veneer, use of projection-based (e.g. HUD) displays which do not intervene in the flow of the interior design, or use of 'smart' 'heritage' materials (e.g. touch sensitive leather armrest)	

In addition to the qualities of experience that have been presented under the categories of manipulation, stimulation, identification and luxury, the design/research focusing on the passenger-oriented car HMI systems should also address the concerns and expectations presented in Table 6.5.

Table 6.5 Other concerns and expectations of the front-seat passengers to be addressed through the infotainment system UX

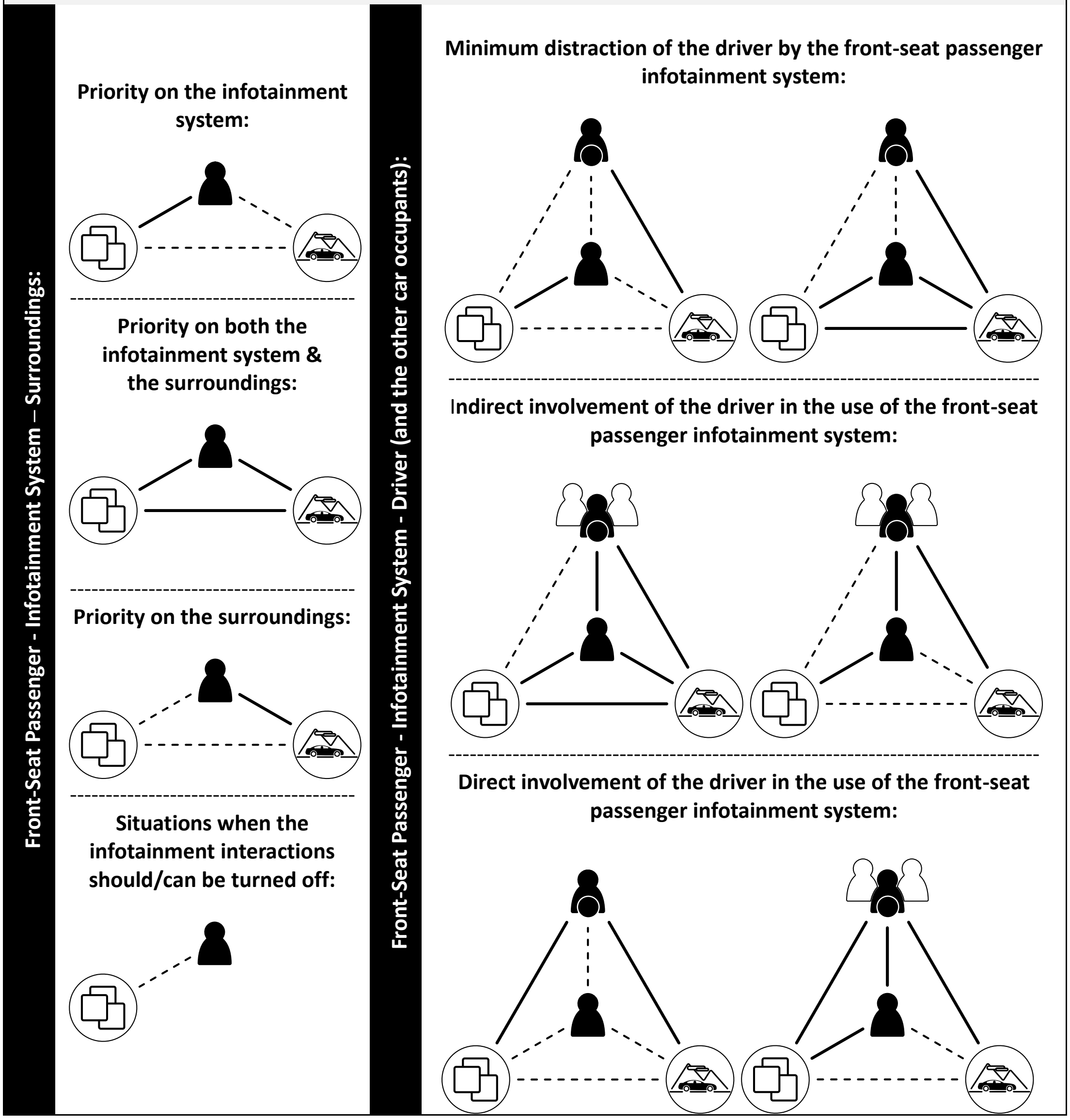
★	*Address the below expectations and concerns of the passengers that were additionally mentioned with regards the front-seat passenger infotainment system UX.*
Extending the WHY:	• **Capturing moments/memories:** Infotainment system's ability to *create* and *capture* memories through camera-like features • **Safety, security:** Prevention of driver distraction, keeping the (front-seat) passenger informed and in-control during the journey • **Prevention of fatigue or physical discomfort:** Enabling front-seat passenger's physical comfort in manipulation of the infotainment system during the journey, providing solutions for the issues like keeping the hand steady during the menu activation or keeping the head up/down for a period due to the fixed position of the displays • **Prevention of motion sickness, nausea:** Reconsidering the interaction aesthetics of the features that require constant attention (e.g. book, games) in a way that it minimize the effects of the dynamic surroundings on users**.** • **Protection of privacy:** Giving the passengers the control over i) the other car occupants' access to their private information/activities (e.g. reading e-mails) through e.g. display visibility adjustments or log-in systems and ii) connectivity by e.g. setting the type and amount of the information shared with the infrastructure

B. Addressing the changes and conflicts in WHY level through HOW & WHAT of the infotainment system interactions

As discussed earlier as part of a framework presented in Section 5.5.5, the front-seat passengers have changing relations with the main actors and components of the front-seat passenger infotainment system, which accordingly alter their expectations from the infotainment system (*why* level). Table 6.6 compiles all possible situations/modes where the other car occupants or the surroundings should be more *involved to / excluded from* front-seat passenger's interactions with the infotainment system. A UX designer/researcher should design such HMI system in a way that it can adapt to each specific mode. To enable this, the analysis provided in Table 5.15 and Table 5.16 demonstrates how each mode can be facilitated through aesthetics of interaction and functionalities in detail (*how* and *what*). However, the system should not only be able to facilitate each mode in isolation, but also enable the flawless transition among these different modes through customisation of the relevant infotainment system aspects. Therefore, the infotainment system should also be connected and context-aware to anticipate the preferences of the passengers and efficiently adapts itself to these changing modes by altering the relevant infotainment system aspects on behalf of the users

Table 6.6 Compilation of the front-seat passenger’s different relations with the main actors and components of the front-seat passenger infotainment system

★ *Consider the below situations that represent the front-seat passenger’s changing relations with the main actors and components of the front-seat passenger infotainment system.*



6.5 Recommendations for the VR prototyping of the car HMI

Table 6.7 provides a roadmap for future car HMI appraisals and present guidance on the prototyping decisions regarding what to prototype (interactive product/system aspects) and how to prototype (medium, scope, fidelity). The recommendations provided in Table 6.7 are based on the researcher’s reflections to the VR simulation that was used in the experience prototyping sessions in the PhD research. Therefore, it first summarizes the decisions taken in the development of the VR simulation that was used for experience prototyping of the infotainment system, then discusses the advantages/disadvantages of these decisions together with their applicability/inapplicability to other types of car HMI appraisals.

Table 6.7 Recommendations for the VR prototyping of the car HMI

WHAT TO PROTOTYPE? – 'FILTERING DIMENSIONS'

Experience prototyping of a car HMI (with VR) required/requires communication of all the relevant aspects of the car HMI in terms of the how and what levels of the interaction. However, the scope and the fidelity levels may vary for each aspect of the car HMI depending on the aim and limitations of the study. These aspects include(d):

- **The what of the car HMI:**
  - functionality
  - content
- **The how of the car HMI/ aesthetics of interaction:**
  - sensory-specific aspects (visual, audio, tactile, kinesthetic aspects)
  - spatio-temporal aspects (communicated through relevant sensory channels)
  - action-reaction aspects (communicated through relevant sensory channels)
  - presentation aspects (communicated through relevant sensory channels)
- **The context (meta)**

HOW TO PROTOTYPE? – 'MANIFESTATION DIMENSIONS'

- **VR set-up (The Medium)**

The equipment/hardware:

- HTC VIVE (VR-HMD) with wireless controllers and base stations (on tripods),
- LeapMotion (hand tracking system) attached to the VR-HMD,
- PC/laptop and keyboard (necessary to run and control the VR demo),
- Speakers
- TV display (or any display) that is connected to the VR-HMD to monitor the users' actions in VE),
- Seat/seating buck.

See Figure 5.1 and Table 5.2 to review the role of each piece of equipment used in experience prototyping sessions of the PhD research.

The software:

- **The game engine:** Unity (version 5.6.3f1)
- **Tracking-VR platform:** SteamVR (version 1515522829) – Steam (package version 1513371133), Unity Package: SteamVR (version 1.2.2)
- **Gesture tracking with LeapMotion:** Leap Developer Kit – Orion (version 3.2.1 – Firmware revision 1.7), Unity Packages (LeapMotion Core_Assets (version 4.3.3), LeapMotion Hands Module (version 2.1.2))

Spatial requirements:

- **Venue size:** VR is 1:1 scale so the venue should provide enough clearance to communicate the spatial boundaries of the car HMI interactions (e.g. as large as the front-cockpit of the car). See Figure 5.1 to view the size of the venue used in experience prototyping sessions of the PhD research.

Other set-up related requirements for the experience prototyping sessions:

- **Simulation sickness control and prevention:** Applying simulation sickness questionnaire before/after the VR demo, encouraging the participants to take off the VR-HMD anytime they feel sick
- **Narrative:** Having a document to be referred while narrating the travel scenario (if applicable), including notes on how to make changes in virtual environment (e.g. change of panorama images with number buttons)
- **Presentation boards:** To be used before/after the VR demo to introduce the participants the basics of the car-HMI design / remind them the interaction scenario that has been experienced in VE.
- **Data collection materials (hardware & software):** Specific to each research, screencasting (e.g. Camtasia) is recommended to record and re-observe participant's actions in VE.

☺ **Advantages / The studies where the set-up is applicable:**

- **Portability (through VR-HMD system):** Ability to conduct the prototyping study in different venues, which cannot be achieved with other stable VR or mixed reality systems (e.g. power walls or driving simulators with heavy/large physical car models)
- **Programmability of the interactions (through the digital prototyping tool)**: Ability to set and alter the parameters for each aspect of interaction aesthetics that can be communicated in digital, which cannot be achieved in paper prototypes
- **Immersion (through VR)**: Presentation of the design solution in the form of a new experience rather than as part of a prototyping session thanks to the participant's detachment from the real environment, which cannot be achieved in same level with the use of UX prototyping apps (tablet/phone) or mixed reality/AR set-ups

☹ **Disadvantage / The studies where the set-up may not be applicable:**

- Inapplicable for the studies with the risk of simulation sickness (e.g. studies which require communication of dynamic environment or longer VR demos)
- Inapplicable for the studies with more complex sensory interactions with the car HMI (e.g. communication of the tactile aspects such as texture)
- Inapplicable for the studies where immersion is not critical (e.g. usability assessments of a tablet application UI)
- Required time for development: Suitable for design iterations only after building the initial VR prototype (Programming the interactions within the VE used in this research took 18 days)

The Scope and Fidelity

WHAT: The functionalities and the content

Elimination of possible sub-functionalities (e.g. only taking a photo through the camera menu but not sharing it), hence the number of interaction tasks and the content; however, keeping the manipulations versatile enough to enable the participants of the user study to evaluate and comment on the aesthetics of interaction of the infotainment system.

☺ **Advantages / The studies where this scope is applicable:**

- Optimisation of the simulation development process, less reliance on the programming support
- Compensation of the fidelity limitations of the simulation hardware / software (e.g. less text to compensate the low visual resolution / lack of physical depth of field, fewer songs to acquire less digital space)
- Lessening the duration of the simulation hence the risk of simulation sickness
- Lessening the length of the experience prototyping session to increase voluntary participation
- Provision of more space for participants to comment on the expansion/enrichment possibilities of the infotainment features

☹ **Disadvantages / The studies where the set-up may not be applicable:**

- Disability to demonstrate all possibilities regarding the interaction flow within the menu structure/information architecture, inapplicable for usability/UX assessments that focus on the navigation within the car HMI design
- Inapplicable for the assessments focusing on the car HMI content

HOW: Visual aspects

Communication of all visual aspects except the material effects (e.g. reflectivity, illumination) of the physical controls and displays, low resolution in GUI which was presented as part of the car (inability of VR to communicate physical depth of field to focus more on the HMI display than the car interior)

☺ **Advantages / The studies where the scope & fidelity are applicable:**

- Applicable for all visual car-HMI assessments (except the ones stated below)

☹ **Disadvantage / The studies where the scope & fidelity may not be applicable:**

- Inapplicable for perceived quality assessments (need of a real-time realistic rendering of the physical components of the car HMI) or assessments focusing on the quality and richness of the visual car HMI content (need to adjust virtual depth of field based on the eye gaze)

HOW: Audio aspects
Communication of all audio aspects (loudness, frequency, timbre) that belong to the digital components of the car HMI but not to the driving context (e.g. engine noise), lack of communication of the source of the audio stimuli
☺ **Advantages / The studies where the scope & fidelity are applicable:** • Applicable for all car-HMI assessments including the interactions with the audio feedback or any audio HMI content (e.g. songs)
☹ **Disadvantages / The studies where the scope & fidelity may not be applicable:** • Inapplicable for any car HMI assessments where the effects of contextual sound are investigated (need to extend the scope of the audio assets) • Inapplicable for any car HMI assessments where the source of the audio stimuli matters (need of a spatial sound system)
HOW: Kinesthetic aspects
Communication of all kinesthetic aspects of gestures (e.g. user's movements, physical effort) based on the communication of the affordances and feedback that guided users while performing gestures (limited with the fidelity of the spatio-temporal and visual aspects), lack of communication of the kinesthetic aspects resulting from the mechanism and material qualities of the physical button (plasticity, rigidity, required force to click)
☺ **Advantages / The studies where the scope & fidelity are applicable:** • Communication of the functionality (activation-deactivation, volume adjustment) of a physical button of the car HMI with the touch-sensitive button of the available VR controller rather than building an interactive physical prototype • Applicable for assessments of gestural interactions with the car HMI
☹ **Disadvantages / The studies where the scope & fidelity may not be applicable:** • Inapplicable for investigation of the kinesthetic interactions of the physical controls of the car HMI (need to involve haptic displays or hi-fidelity physical props) • Inapplicable for investigation of the gestures that would be performed beyond the tracking area of the LeapMotion (need to position the tracking system where all gestures can be viewed)
HOW: Spatio-temporal aspects
Communication of all spatial aspects (spatial distribution of interface elements, reach) and movements in life-size 1:1 scale, fidelity is limited with the frame rate of the simulation and the precision of both LeapMotion and VIVE tracking systems.
☺ **Advantages / The studies where the scope & fidelity are applicable:** • Applicable for the assessments of all spatio-temporal aspects of the car HMI
☹ **Disadvantages / The studies where the scope & fidelity may not be applicable:** • Inapplicable for investigation of the gestures that would be performed beyond the tracking area of the LeapMotion (need to position the tracking system where all gestures can be viewed)

The context: The surroundings
• Static vs. dynamic approach: Use of still panorama images of selected locations to be changed by the researcher consecutively during the VR demonstration • Exclusion of the other sensory stimuli that result from the road conditions (e.g. shakiness of the car on a bumpy road, traffic noise) • Limitations in fidelity of still panorama images (need of higher resolution than 13312x6656 to apply Google Street View panorama images as textures to the circular plane surrounding the virtual car to create a life-size image in VE)
☺ **Advantages / The studies where the scope & fidelity are applicable:** • Simulation of a real travel scenario, increased realism with the use of still panorama images from existing locations • Communication of long journeys in limited time through static vs. dynamic approach • Acquiring less digital space in VR system in comparison with the use of dynamic content (e.g. dynamic 3D environment, panoramic video footage) • Applicable for studies where the surroundings information and geo-references play an important role excluding the below
☹ **Disadvantages / The studies where the scope & fidelity may not be applicable:** • Inapplicable for exploring the effects of dynamic car/environment on the car HMI UX (need to integrate dynamic 3D environment, panoramic video footage in VE) • Inapplicable for exploring the effects of the road conditions on the car HMI UX (need to integrate mixed reality approach to communicate the haptic effects of the road conditions)
The context: The car interior
Inclusion of the front cockpit and rear seats without photorealistic rendering of the car interior (except assignment of material textures to communicate specific materials such as wooden veneers used in passenger dashboard)
☺ **Advantages / The studies where the above scope & fidelity are applicable:** • Communication of the HMI interactions within the 3D space defined by the car interior (e.g. if the pointing gestures work whilst the user is resting his/her arm on the armrest) • Enabling participants to position themselves as the car occupants
☹ **Disadvantages/ The studies where the scope & fidelity may not be applicable:** • Inapplicable for perceived quality assessments (need of a real-time realistic rendering of the physical components of the car HMI)
The context: The car occupants
☺ Lack of 2D/3D visual representation of any car occupants (e.g. use of imagination for driver's presence), use of virtual hands (low-poly 3D models provided in LeapMotion - HandsModule Unity package) to demonstrate participants' hand gestures in VR
Advantages / The studies where the scope & fidelity are applicable: • Ability to achieve presence through representation of the body part that is most involved in HMI interactions
Disadvantage / The studies where the scope & fidelity may not be applicable: • Inapplicable for experience prototyping of the car HMI where the other car occupants are actively involved in HMI interactions (may need to include them as the second participant using another VR-HMD with their virtual representation)

6.6 Contributions to Knowledge

Previous sections introduced the ways the PhD research contributed to knowledge whilst presenting the answers to the research questions. This section will reorganize them by specifying the research's contributions regarding i) examination of underlying principles that define luxury front-seat passenger UX, ii) design of concepts for automotive passenger HMI infotainment systems based on luxury UX specifications, and iii) methods and implementation of experience prototyping through VR.

- **Examination of underlying principles that define luxury front-seat passenger UX**:

This research was the first study in automotive UX literature that enabled users to try and reflect on a front-seat passenger-oriented infotainment system solution in a luxury car context. Through the analysis of participants' evaluations of the design proposal in experience prototyping sessions, it presented key design considerations to be referred in development of the future (luxury) front-seat passenger infotainment systems. The analysis was based on the investigation of the links among the *why, what* and *how* levels of luxury front-seat passenger infotainment interactions. To do so, it also defined what each level comprises in the context of luxury front-seat passenger infotainment systems.

In why level, definitions of what comprises luxury interaction/experiences were generated both through the literature review synthesis and the analysis of the experience prototyping study. The contributions can be listed as the following:

Deconstruction of the why through relations between UX and luxury values: There has not been academic studies elaborating the interactive systems and the concept of luxury together. This PhD thesis provided a comparison of the qualities of user experience in the UX literature with the luxury values in the marketing literature. It discussed and visualised the corresponding terminology to be able to refer to the luxury values within the context of interactive systems.

Extending the why with alternative keywords and concepts to define pleasant user experience for front-seat passenger infotainment systems: The analysis of the experience prototyping study revealed a list of expectations and concerns that were additionally mentioned in relation to the semantic differential pairs provided in UX evaluation. These keywords and concepts were categorized under relevant qualities of experience (e.g. stimulation) and can be utilized by UX designers/researchers as alternative criteria/checklist to deliver a specific quality to the user.

Identification of the qualities of experience that are most related with the manifestation of luxury: The analysis of the experience prototyping study revealed a list of UX dimensions that are most associated with luxury, to be used by UX designers/researchers as criteria/checklist to define the expectations from luxury car HMI and such luxury product-service-systems.

In **what & how level**, the PhD research provided a specification of what comprises the luxury infotainment system:

Deconstruction of the interactive products/systems: The thesis synthesized the product experience and aesthetics of interaction literature to define the dimensions of the *how* and *what* levels of interaction, combining both sensory-specific and non-sensory specific aspects of interaction in the literature to tackle the complexity of infotainment systems both as user interfaces and as parts of the car interior. It also provided the visualization of the synthesis with demonstration of the relationship among the aesthetics of interaction (*how*) categories. These interactive product/system aspects can be referred in any design and research process where deconstruction of an interactive system/product is needed. This research demonstrated how this synthesis can become useful through several practical phases: i) while discussing the simulation challenges of the interaction technologies based on the aspects of interaction they point out, ii) while deciding what to prototype and how to prototype (definition of the scope, medium, fidelity for each aspect of the infotainment system), and most importantly iii) while coding the participants' comments about the infotainment system to identify exactly which aspect plays role in negative or positive appraisals.

Specification of potential functionalities and interactions for luxury front-seat passenger infotainment system: The research provided the review and analysis of the contemporary academic and industrial efforts to empower (front-seat) passengers through car HMI and revealed the information, entertainment and communication needs that are identified and/or targeted in literature and in concept HMI systems. The analysis also identified control and display technologies that are potential to be embodied in front-seat passenger infotainment system. The findings are then reflected onto a design proposal and its VR prototype. The analysis of the participant's reflections on the design proposal demonstrated which functionalities or which interaction aspects are more promising to deliver a luxury passenger UX as well as how to extend, recontextualize and develop the solutions provided in the design proposal (See Section 5.5.4 for suggestions for functionalities and aesthetics of interaction).

Please find the concise design recommendations for new infotainment functionalities and interactions that address the main expectations and concerns of the front-seat passengers (linking the *why, what* and *how* of front-seat passengers' infotainment interactions) in Section 6.4 The recommendations also include utilization of the framework that conceptualizes front-seat passenger's changing roles and relations with the infotainment system. Please see Table 6.6 for representation of these different modes/situations where the front-seat passengers prioritize their relationship with the driver (and other car occupants) and their surroundings in different levels. Section 5.5.5 of the thesis (See Table 5.15 and 5.16) provides a list of suggestions to address the requirements of each mode/situation through functionalities and aesthetics of interaction of the luxury front-seat passenger infotainment system.

- **Design of concepts for automotive passenger HMI infotainment systems based on luxury UX specifications:**

  The contribution resides in the specification and design of a new infotainment system, in collaboration with Bentley Motors. The design process included development of a travel scenario which reflects the explorative nature of GT travels and proposal of new functionalities, content and interactions that would fit to such travel scenario and qualities of luxury experience that were identified in literature so far. The design presented how specific control and display technologies like gesture recognition, HUDs and TOLED can be applied to front-seat passenger infotainment system. It also demonstrated an application of the brand identity / design language of the brand's previous drive HMI solutions to the front-seat passenger infotainment system.

- **Methods and implementation of experience prototyping through VR:**

  In the literature the use of VR in UX evaluation is limited with usability assessments. The PhD research approached to VR as a means of immersive communication of the aesthetics of interaction, functionalities and the context of the infotainment system within a travel scenario and investigated their relationship with both pragmatic and hedonic qualities of experience. Therefore, the contribution rests on both the development of a new virtual environment/simulation for a car-HMI appraisal and presentation of a more effective use of the potentials of VR (e.g. immersion) by administering UX-oriented appraisal methods to VR prototyping rather than limiting its use to applications like objective task performance measurements.

The recommendations to guide VR prototyping decisions regarding what to prototype and how to prototype in car-HMI appraisals can be found in Table 6.7. The recommendations provide a roadmap for future applications regarding: i) use of interactive product/system aspects (the synthesis) as new filtering dimensions; ii) definition of the medium based on what to prototype and deciding the scope and fidelity for each aspect of the infotainment system, iii) the applicability of the decisions taken in development of VR in this PhD research to other car HMI appraisals.

6.7 Contributions to the Research Partners

- **Virtual Engineering Centre (VEC):** The VEC had been involved in automotive design projects through creation of bespoke immersive environments to support product design, manufacturing and process development and training (VEC, 2018). Aside from the engineering-focused applications, the scope of the product design projects mainly included perceived quality and ergonomics assessments of the car interior. In this regard, the PhD project provided the VEC with an innovative vision in use of their facilities through integration of VR simulation to experience prototyping. The special emphasis on the communication of interaction aesthetics and functionalities pushed the limits of their programming skills to achieve a presentable demonstration to both research participants and the industrial partner of the project - Bentley Motors. This experience is expected to be useful for the VEC in future collaborations with the automotive companies on HMI appraisal projects.

- **Bentley Motors:** The contribution of the research outcomes to the industrial partner is related with both design and prototyping of the front-seat passenger infotainment system as described in the following:

With regards to design, the research delivered a front-seat passenger infotainment system proposal that was designed with reference to the findings of the comprehensive technology and literature review. The design also demonstrated an application of the brand identity / design language of the brand's previous drive HMI solutions to the front-seat passenger infotainment system, which was appreciated by the Bentley Motors HMI design team as well as the research participants ('consistency with the luxury car interior'). However, the main role of design and simulation in this research was to investigate the UX contributions of the infotainment system with participation of the users. Therefore, the major design contribution of the research to Bentley Motors was the analysis of the user study and demonstration of the design considerations for the future luxury front-seat passenger infotainment systems. In addition to the research participants of experience prototyping study, three members of Bentley Motors HMI design team tried out the VR simulation, which enabled them to explore the design solutions in an immersive and interactive way.

With regards to experience prototyping through VR, the research demonstrated a way to appraise HMI systems without investing in application of the interaction technologies in concept development phase. Apart from its financial advantages, the HMI design team also mentioned that this simulation could be a very effective communication tool within the company. It could facilitate decision making with other departments (e.g. marketing) on introduction of new features or investment in a new technology.

6.8 Limitations of the Research

The limitations of the research can be explained under two headings: theoretical limitations, and practical (methods-related) limitations.

The theoretical limitations include:

- The lack of academic studies elaborating the interactive systems and the concept of luxury together: This limitation was tackled with the comparison of the qualities of pleasant user experience in the UX literature with the luxury values in the marketing literature. Based on the corresponding terminology, the research made use of the metrics that exist in UX literature to define luxury experience. Therefore, in this research, luxury could not be elaborated in isolation. However, this limitation turned into a requirement for the unprecedented front-seat passenger infotainment systems because there was also a need to explore what makes these new infotainment experience pleasant for the front-seat passengers.

The practical limitations are mostly related with the use of VR simulation for experience prototyping as described in the following:

- The interaction technologies to be applied into the design was limited with the ones that can be prototyped with simulation (within the VEC). This limitation resulted in underexplored potentials of the eliminated technologies for the infotainment system design. The scope of the interaction aspects (that was explored in relation to luxury) was limited with the technologies offered in the final design proposal and VR simulation.

- The scope of the functionalities, content and the number of interaction tasks in VR simulation had to be limited to minimize the duration of the simulation (simulation sickness) and to lessen the programming effort required. However, this limitation was advantageous in the sense that it provided more space for the participants to suggest new features.

- The resolution of surroundings images and the GUI text used in VR simulation was lower than planned due to the technical limitations, which affected the UX evaluation questionnaire results. However, since the participants were also asked which interaction aspects affected their ratings the most, it was possible to differentiate the ones that are affected by the simulation medium (e.g. resolution, shakiness of the pointer) from the other aspects.

- In VR simulation, the 2.5-hours-journey was communicated in 10-15 minutes with the consecutive use of static panorama images chosen from several real locations. Use of the static environment had implications for the research that the effects of dynamic environment on infotainment interactions had to be left out of the scope. However, this application was a more easy-to-deliver yet realistic alternative to the use of dynamic car in 3D environment or to panoramic videos. It also minimized the risk of simulation sickness.

6.9 Implications of the Research

The implications of the research to design theory and practice are not confined to the front-seat passenger infotainment systems. The contributions of the research have also implications in the fields of automotive HMI, UX design, industrial design and in design of other luxury products-services-systems.

For example, the investigation of the qualities of experience (e.g. being state-of-the-art) and infotainment system aspects that were associated with luxury (e.g. greeting animations with the brand logo, transparent screen overlaid on the wooden veneer) can be referred in user interface design of the high-segment consumer products and luxury automotive HMI.

The analysis of the front-seat passengers' infotainment experience is also applicable to autonomous cars where the driver becomes a front-seat passenger. Since the future of mobility is autonomous, Section 6.9.1 is dedicated to the discussion on the research's applicability to autonomous vehicle HMI.

Experience prototyping through VR is applicable to any design project that requires immersive and interactive prototyping of the product in different spatial-temporal contexts (e.g. use of travel app. in different locations of the city).

6.9.1 Applicability of the Research Findings to Future Autonomous Car HMI

As stated above, the findings of the research are also applicable to autonomous car HMI/infotainment system design and development, if we exclude the discussions regarding the distinction between the driver and passenger (e.g. driver's distraction by the passenger, co-navigation). The infotainment features and interactions that were provided as part of the front-seat passenger infotainment system solution and extended through the analysis of participant's suggestions also apply to autonomous car HMI. However, the researchers who would like to reflect the findings of the PhD research to autonomous car HMI development should check which design decisions/recommendations were associated with which motivations or concerns of the front-seat passengers. For example, elimination of the audio feedback or keeping the range of gestures minimum to avoid driver distraction may not be relevant for autonomous car HMI. On the other hand, prevention of passenger's distraction through customisation of the aesthetics of the notification interactions (e.g. size, timing) and the content constitutes a very significant design consideration for the future connected car HMI of autonomous vehicles. In addition, the infotainment system is more likely to be a shared system in the autonomous driving context. Therefore, some design recommendations targeting ‘collaboration’ in navigation tasks will need to be reinterpreted for collaboration in the use of infotainment system (e.g. media selections) such as enabling visibility of the HMI display from different point of views.

Another contribution of this research which constitutes a reference for autonomous car HMI is the framework that conceptualizes the front-seat passenger’s changing role and relations with the infotainment system. While considering the passenger experience in autonomous cars, UX designers can make use of the design suggestions provided to facilitate different modes where front-seat’s passengers prioritize their interactions with their surroundings or the infotainment system in different levels. The distinction between the driver and the front-seat passenger can be eliminated in autonomous cars. Therefore, the modes that are investigating the involvement of driver in the use of infotainment system may not be applicable for fully-autonomous car HMI, but they are still relevant for semi-autonomous driving scenarios.

6.10 Further Research

Further research directions and opportunities include redesigning the infotainment system with integration of other interaction technologies (e.g. eye gaze recognition to support gestural input) and investigating their interaction aesthetics with regards to luxury experience. The framework that conceptualizes the front-seat passenger’s changing roles and relations with the infotainment system can be expanded by including more actors and components with a special focus on internet of things and connectivity (e.g. smart-home becoming a component of your infotainment experience).

Another research proposal can be built on one of the simulation-related limitations of the research, such as communication of dynamic environment in the same travel scenario and exploration of its effects on UX appraisals. Future studies can also explore the use of other simulation technologies (e.g. AR, CAVE) for experience prototyping or comparison of the interaction prototyping capabilities of the two different simulation options. Regarding the simulation development process, there is also a research opportunity in use of game engines (e.g. Unity) in immersive prototyping of complex user interfaces. The existing UI tools can be expanded with inclusion of default animations and/or specialized plug-ins to lessen the required programming effort.

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APPENDIX 1. The list of the car models that are included in the technology review

Concept cars are written **bold.** The cars selected for the detailed technology review are **highlighted.**

Frankfurt Motor Show 2015*	
1. ALFA ROMEO-Giulia	**26. MERCEDES-BENZ-IAA concept**
2. AUDI-A4	**27.** MERCEDES-BENZ-C-class Coupe
3. AUDI-S4	**28.** MERCEDES-BENZ-C63 AMG Coupe
4. AUDI-QE-tron SUV concept	**29.** MERCEDES-BENZ-C63 AMG Coupe 'Ed. 1'
5. BENTLEY MOTORS-Bentayga	**30.** MERCEDES-BENZ-C63 DTM race car
6. BMW-3-series	**31.** MERCEDES-BENZ-S-class Convertible
7. BMW-7-series	**32.** MINI-Clubman estate
8. BMW-X1	**33. NISSAN-Gripz crossover concept**
9. BMW-M6 GT3 race car	**34.** NISSAN-NP300 Navar
10. BUGATTI-Vision Gran Turismo	**35. PEUGEOT-Fractal concept**
11. CITROEN-Cactus M	**36. PORSCHE-Mission-E concept**
12. CITROEN-DS4 Hatch/Crossback	**37.** PORSCHE-911 991.2 Carreras
13. FERRARI-488 Spider	**38.** RENAULT-Megane
14. FIAT-500	**39.** RENAULT-Talisman
15. FORD-SUV (facelifts)	**40.** ROLLS-ROYCE-Dawn
16. HONDA-Project 2&4 concept	**41.** SEAT-Ibiza Cupra
17. HYUNDAI-i20 WRC rally car	**42.** SEAT-Leon Cupra 290
18. HYUNDAI-N 2025 Vision Gran Turismo	**43.** SEAT-Leon Sport Cross
19. INFINITI-Q30	**44.** SMART-Fortwo
20. JAGUAR-F-Pace SUV	**45.** SUZUKI-Baleno
21. KIA-Sportage	**46.** TOYOTA-Prius
22. KIA-Ceed	**47.** VAUXHALL/OPEL-Astra hatchback
23. LAMBORGHINI-Aventador SV Roadster	**48.** VAUXHALL/OPEL-Astra Sports Tourer
24. LAMBORGHINI-Huracan Spyder	**49.** VOLKSWAGEN-Golf GTI Clubsport
25. MAZDA-Koeru	**50.** VOLKSWAGEN-Tiguan 50

*Based on the list "Frankfurt Motor Show 2015: A-Z Preview of All the New Cars" presented in Car Magazine (2015).

Geneva Motor Show 2015**	
1. ABARTH-500 range	**47.** LAND ROVER-Range Rover Evoque
2. ALFA ROMEO-4C Spider	**48.** LAND ROVER-Range Rover Evoque Convert.
3. ASTON MARTIN-DBX crossover concept	**49.** LEXUS-LF-SA
4. ASTON MARTIN-Vantage GT3	**50.** LEXUS-GS-F
5. ASTON MARTIN-Vulcan	**51.** LOTUS-Evora 400
6. AUDI-R8 supercar	**52. MAGNA STEYR-Mila Plus concept**
7. AUDI-Prologue	**53.** MAZDA-CX-3
8. AUDI-RS3 Sportback	**54.** McLAREN-675 LT Longtail
9. BENTLEY MOTORS-EXP 10 Speed 6	**55.** McLAREN-P1 GTR
10. BENTLEY MOTORS-Continental GT	**56.** MERCEDES-BENZ-Maybach S600 Pullman
11. BMW-2-series Gran Tourer	**57.** MERCEDES-BENZ-AMG GT3
12. BMW-1-series	**58. MERCEDES-BENZ-G500 4x4^2**
13. BMW-6-series	**59. MITSUBISHI-Concept XR-PHEV II**
14. BMW-M4 Coupe Moto GP safety car	**60.** MITSUBISHI-L200 pick-up
15. BORGWARD-Borgward	**61.** MORGAN-Aero 8
16. BUGATTI-Veyron #450	**62.** NANOFLOWCELL-Quant F
17. CITROEN-DS5	**63. NISSAN-Sway**
18. CITROEN-Berlingo Multispace	**64.** PEUGEOT-208
19. DACIA-Concept	**65. PHIARO-P75 Cypher Concept**
20. DFSK-C37	**66.** PORSCHE-911 GT3 RS
21. EDAG-Light Cocoon	**67.** PORSCHE-Cayman GT4
22. FERRARI-488 GTB	**68.** QUOROS-3 City SUV

23. FORD-Focus RS
24. FORD-GT supercar
25. FORD-Edge Sport
26. HONDA-Civic Type R
27. HONDA-NSX
28. HONDA-HR-V
29. HONDA-Jazz
30. HYUNDAI-Tucson
31. HYUNDAI-i20 Coupe
32. HYUNDAI-i30
33. HYUNDAI-i40
34. IED-Syrma concept
35. INFINITI-QX30 concept
36. INFINITI-Q60 concept
37. ITALDESIGN-Giugiaro Gea concept
38. JAGUAR-XF R-Sport Black
39. KAHN-Flying Huntsman 6x6
40. KIA-Sportspace concept
41. KIA-Picanto
42. KIA-Ceed GT Line
43. KIA-New 1.0 three-cylinder turbo
44. KOENIGSEGG-Agera RS
45. KOENIGSEGG-Regera
46. LAMBORGHINI-Aventador SV
69. RADICAL-RXC Turbo 500
70. RENAULT-Kadjar
71. RENAULT-Alpine Gran Turismo concept
72. RENAULT-Clio RS 220 Trophy
73. RENAULT-Zoe update
74. RINSPEED-Budii
75. ROLLS-ROYCE-Serenity
76. SEAT-20V20 concept
77. SEAT-Leon ST Cupra 280
78. SKODA-Superb
79. SKODA-Octavia vRS 230
80. SSANGYONG-Tivoli
81. TOURING-Superleggera Berlinetta Lusso
82. TOYOTA-Auris
83. TOYOTA-Avensis
84. VAUXHALL/OPEL-Corsa VXR
85. VAUXHALL/OPEL-Viva
86. VAUXHALL/OPEL-OnStar
87. VOLKSWAGEN-Sport Coupe Concept GTE
88. VOLKSWAGEN-Golf GTD Estat
89. VOLKSWAGEN-Sharan
90. VOLKSWAGEN-Passat
91. VOLVO-XC90 R-Design
92. VOLVO-S60 Cross Country
93. VOLVO-V60 Cross Country

** Based on the list "Geneva Motor Show 2015: A-Z Preview of All the New Cars" presented in Car Magazine (2015).

Geneva Motor Show 2016***

1. ABARTH-124 Spider
2. ALFA ROMEO-Giulia
3. ALFA ROMEO-Giulietta
4. ARASH-AF10
5. ASTON MARTIN-DB11
6. AUDI-Q2
7. AUDI-S4 Avant
8. BENTLEY MOTORS-Mulsanne
9. BMW-M760Li xDrive
10. BMW-Vision Next 100
11. BUGATTI-Chiron
12. CITROEN-SpaceTourer Hyphen
13. FERRARI-GTC4 Lusso
14. FIAT-124 Spider
15. FIAT-Tipo
16. FORD-Fiesta ST200
17. FORD-Kuga
18. FORD-Vignales for all
19. HONDA-Civic
20. HONDA-FCX Clarity hydrogen car
21. INFINITI-Q60 sports coupe
22. INFINITI-QX30 Premium Active
23. JAGUAR-F-type SVR
24. KIA-Optima Sportswagon
25. KIA-Niro concept
26. KOENIGSEGG-Regera
27. LAND ROVER-Range Rover Evoque Cabrio
28. LAMBORGHINI-Centenario
36. McLAREN-MSO P1
37. McLAREN-675LT
38. MERCEDES-BENZ-C-class Cabriolet
39. C43 AMG Coupe
40. MITSUBISHI-ASX
41. MITSUBISHI-L200
42. MORGAN-4/4 80^{th}
43. MORGAN-EV3
44. PAGANI-Huayra BC
45. PEUGEOT-2008
46. PEUGEOT-Traveller and i-Lab
47. PININFARINA-H2 Speed concept
48. PORSCHE-718 Boxster
49. PORSCHE-911R
50. RENAULT-Megane Sport Tourer
51. RENAULT-Scenic
52. RINSPEED-Etos
53. SEAT-Ateca
54. SKODA-Vision S
55. SMART-Fortwo Cabrio Brabus Edition
56. SSANGYONG-Tivoli XLV
57. SSANGYONG-SIV-2
58. SUBARU-XV concept
59. TECHRULES-TREV supercar concept
60. TESLA-Model X crossover
61. TOYOTA-RAV4
62. VAUXHALL/OPEL-GT concept

29. LEXUS-LC 500 coupe **30.** LEXUS-LC 500h coupe **31.** LOTUS-Elise Cup 250 **32.** MASERATI-LevantE **33.** MAZDA-RX-Vision **34.** MAZDA-3 SkyActiv-D 1.5 **35.** McLAREN-570GT	**63.** VAUXHALL/OPEL-Mokka X **64.** VAUXHALL/OPEL- Astra **65.** VOLKSWAGEN-Phideon **66.** VOLKSWAGEN-T-Cross Breeze **67.** VOLKSWAGEN-Tiguan **68.** VOLKSWAGEN-Up **69.** VOLVO-V40 **70.** VOLVO-V90 estate
*** Based on the list "Geneva Motor Show 2016: A-Z Preview of All the New Cars" presented in Car Magazine (2016).	
Consumer Electronics Show (CES) 2015 ****	
1. BMW-İ3 **2.** BMW-İ8 **3. BMW M4 Concept Iconic Lights** **4.** CHEVROLET-Corvette Stingray Z06 **5. ELIO MOTORS-The Elio concept** **6.** FORD-Focus ST **7.** FORD-Mustang **8.** JEEP-Wrangler **9.** JEEP-Wrangler Jensen/DUB **10. MERCEDES-BENZ-F015 Luxury in Motion** **11.** TOYOTA-Mirai hydrogen FCEV **12.** VOLKSWAGEN-e-Golf **13. VOLKSWAGEN-Golf R Touch** **14.** RENOVO-Coupe	
**** Based on the list "The cars of CES 2015" presented in Cnet (2015).	
Consumer Electronics Show (CES) 2016 *****	
1. AUDI-E-Tron Quattro **2. BMW-i8 Vision (Future Interaction)** **3.** CHEVROLET-Bolt EV **4. FARADAY FUTURE-FFZERO1** **5.** FORD-GT **6. FORD-Fusion Hybrid Autonomous Test Car** **7. KIA-Drive Wise** **8. MCLAREN-675LT JVC Kenwood** **9. TOYOTA-FCV Plus concept** **10. TOYOTA-FV2 concept** **11. TOYOTA-Kikai concept** **12. VOLKSWAGEN-BUDD-e concept** **13. VOLKSWAGEN-e-Golf Touch** **14. VOLVO-Concept 26**	
***** Based on the list "The 10 Best at CES 2016" presented in BBC (2016) and "The 10 Coolest Cars of CES 2016" presented in PC Mag (2016) and "The 12 coolest concept cars at CES" presented in Business Insider (2016).	

APPENDIX 2. Simulation sickness questionnaire (original)

No______________ Date____________________

SIMULATOR SICKNESS QUESTIONNAIRE
Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

APPENDIX 3. Participant information sheet (focus group)

UNIVERSITY OF LIVERPOOL

Exploration of Simulation Challenges of User Interfaces with VEC

[Version 2, February 2017]

You are being invited to participate in a research study. Before you decide whether to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and feel free to ask us if you would like more information or if there is anything that you do not understand. We would like to stress that you do not have to accept this invitation and should only agree to take part if you want to. Thank you for reading this.

The Purpose of the Study:
This study is conducted as a part of a PhD research entitled as "Empowering Front-Seat Passenger: Design and Prototyping of Luxury Infotainment Interactions through Effective Use of Simulation Technologies". This PhD is conducted in collaboration with VEC (Virtual Engineering Centre) and a UK-based car manufacturer. It aims to design automotive user interfaces specific to front-seat passengers of a luxury car and to prototype front-seat passengers' interactions with these interactive systems through simulation. To do so, it was necessary to understand the current trends in automotive user interfaces. Therefore, a technology review has been conducted through exploration of concept cars presented in particular auto-shows in 2015-2016. Now, we have a list of different types of user interfaces/interaction technologies for input (e.g. gesture recognition) and information provision (e.g. head-up displays), prospected for future cars. In this study, participants (All of them are VEC staff) will be asked their expert opinion on simulation challenges and opportunities for each user interface type/ technology in this list. This study will enable us to identify the most promising interfaces/interaction technologies for design & interaction prototyping processes. After this stage of the study is completed, outcomes will be analysed to decide which technologies are most promising to integrate in the following stage of the study. Your views will be anonymised and will be shared with the UK-based car manufacturer (in relation to PhD collaboration).

Participants of the Study:
You are invited to this study as VEC staff who have expertise in simulation development (visualization and software development), who are familiar with the related equipment, and/or who are the decision makers of any investment in simulation technology.
We would like to remind that participation is voluntary and that participants are free to withdraw at any time without explanation and without incurring a disadvantage.

Structure of the Study:
This PhD research is conducted by the PhD student Guzin Sen under the supervision of Dr. Bahar Sener- Pedgley. This study will be conducted as a focus group including a mini-questionnaire to be filled in during the session. It will be led by Guzin Sen and the whole session is expected to take approximately 2,5 hours with a 10-minutes break in the middle. It consists of following steps:

• **Presentation (app. 20 min):** Introduction of the technologies/interfaces
• **Completion of the chart (app. 120 min):** The chart consists of list of technologies/user interfaces, and the sketches that exemplify possible applications of these technologies to front-seat passenger area. Each technology/user interface will be discussed through: **1. Capabilities of VR Simulation:** What aspects of interaction can be communicated or tracked? **2. Challenges of/for VR Simulation:** What aspects of interaction could be challenging to communicate or track?

3. a. Required degree of reality (virtual reality or mixed reality) for interaction prototyping
3. b. Need of equipment/spatial settings for interaction prototyping

You will be asked to write down your answers on the chart. You can refer to the list of different aspects of interaction (sensory modality specific aspects, spatio-temporal aspects etc.) and the list of simulation equipment/spatial settings provided.

----

4. The mini-questionnaire: Capabilities of VEC
You will be asked to rate the possibility of simulation/prototyping of each technology/user interface by a mini-questionnaire including the below criteria:

- Availability of necessary equipment/settings
- Cost/Need of investment
- Existence of relevant experience of VEC Staff
- Required time for development
- Added value to VEC (Motivation of VEC to invest in)
- Range of application within industry

Wrap-up, final remarks (app.10 min)

Risks in taking part:
There are not any perceived disadvantages or risks involved in this study.

What if I am unhappy or if there is a problem?
If you are unhappy, or if there is a problem, please feel free to let us know by contacting the principal investigator/supervisor Dr. Bahar Sener-Pedgley (see contact details below) and we will try to help. If you remain unhappy or have a complaint which you feel you cannot come to us with then you should contact the Research Governance Officer at ethics@liv.ac.uk. When contacting the Research Governance Officer, please provide details of the name or description of the study (so that it can be identified), the researcher(s) involved, and the details of the complaint you wish to make.

Benefits in taking part:
With this study, we will identify the promising user interfaces/interaction technologies to be prototyped with simulation in VEC. The discussions can contribute to expansion of the capabilities of the centre in product development projects by exploring new technologies and/or new visions in simulation.

Will my participation be kept confidential? What will happen to the results of the study?
A voice recorder will be used to capture all comments made during the session. After the session, I (Guzin Sen) will collect all hand-filled hard copy documents (chart and questionnaire) and safely store them within my locked file cabinet at the office. All digital data will be transferred to UoL M-Drive and safely secured. Your names will be anonymised (e.g. Participant 1: Software Developer) in data arrangement and presentation of results. The findings of this study can be used in research reports, conference presentations, publications and my PhD dissertation. The data will be only available to the student investigator and supervisor until the end of PhD research (28 FEB 2019) and then permanently deleted/destroyed. The feedback of the findings of the study can be shared with you at your request in the format of a written report.

For further information:

Principal Investigator/Supervisor
Dr. Bahar Sener-Pedgley
University of Liverpool, Division of Industrial Design
Brodie Tower R. 209, L3 5DA, Liverpool, UK
bsener@liverpool.ac.uk

Student Researcher
Guzin Sen
University of Liverpool, Division of Industrial Design
Brodie Tower R. 212, L3 5DA, Liverpool, UK
guzinsen@liverpool.ac.uk

APPENDIX 4. Participant consent form (focus group)

UNIVERSITY OF LIVERPOOL

Committee on Research Ethics

PARTICIPANT CONSENT FORM

Title of Research Project: Exploration of Simulation Challenges of User Interfaces with VEC

Researcher(s): Dr. Bahar Sener-Pedgley (Supervisor)
Guzin Sen (Student Researcher)

Please initial box

1. I confirm that I have read and have understood the information sheet dated [DATE] for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐

3. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish. ☐

4. I understand and agree that my participation will be audio recorded and I am aware of and consent to your use of these recordings in the analysis of the study. The audio recording will only be available to the student researcher and the supervisor and will not be shared with third parties. ☐

5. I understand and agree that what I have said or written as part of this study will be used in reports, publications and other research outputs where my identity will be anonymised as participant number, profession e.g. participant 1, software developer. ☐

6. I agree to take part in the above study. ☐

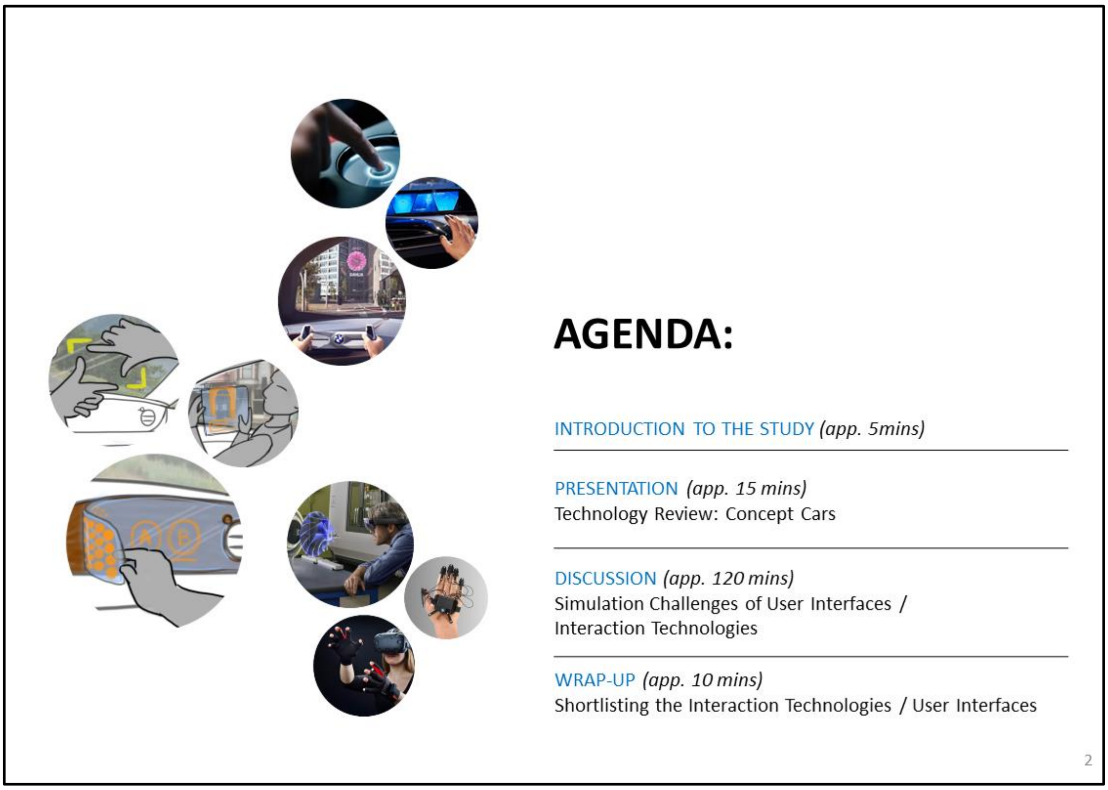
Participant Name	Date	Signature
Name of Person taking consent	Date	Signature
Researcher	Date	Signature

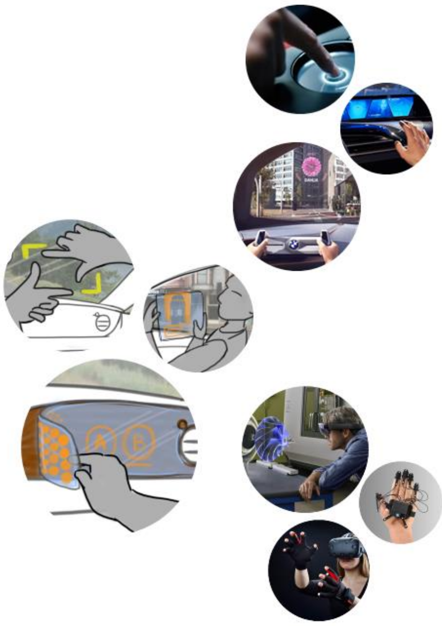
Principal Investigator/Supervisor
Dr. Bahar Sener-Pedgley
University of Liverpool, Division of Industrial Design
Brodie Tower R. 209, L3 5DA, Liverpool, UK
bsener@liverpool.ac.uk

Student Researcher
Guzin Sen
University of Liverpool, Division of Industrial Design
Brodie Tower R. 212, L3 5DA, Liverpool, UK
guzinsen@liverpool.ac.uk

[Version 2 & February 2017]

APPENDIX 5. Presentation slides (focus group)





AIM:

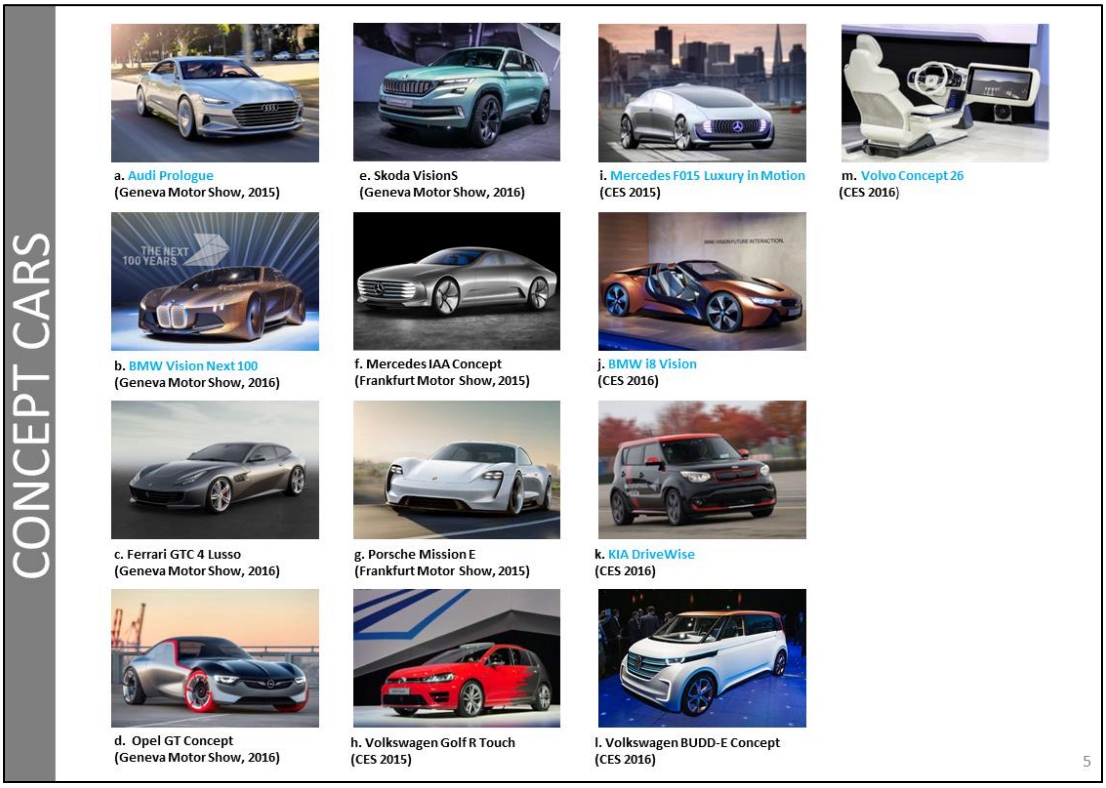
- To understand what aspects of interaction are challenging to communicate, track and modify with simulation for each interaction technology / user interface.
- To shortlist the interaction technologies / user interfaces for front-seat passenger infotainment system design which will be prototyped with simulation

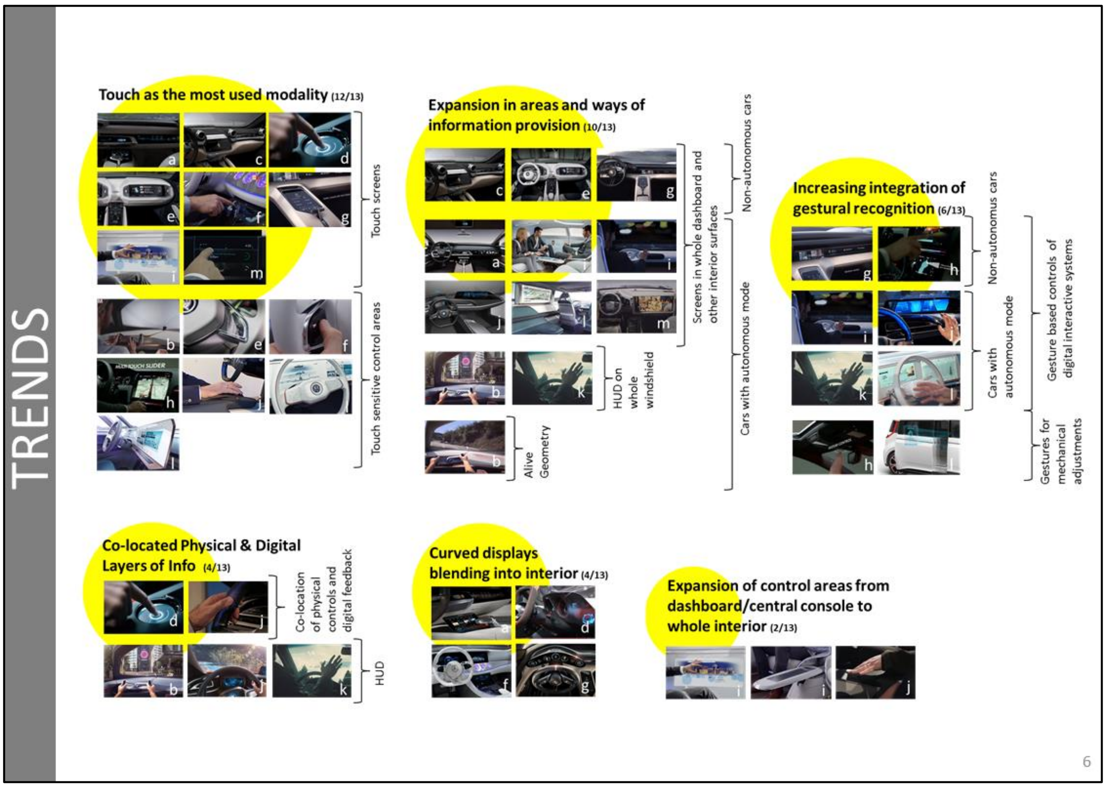
3

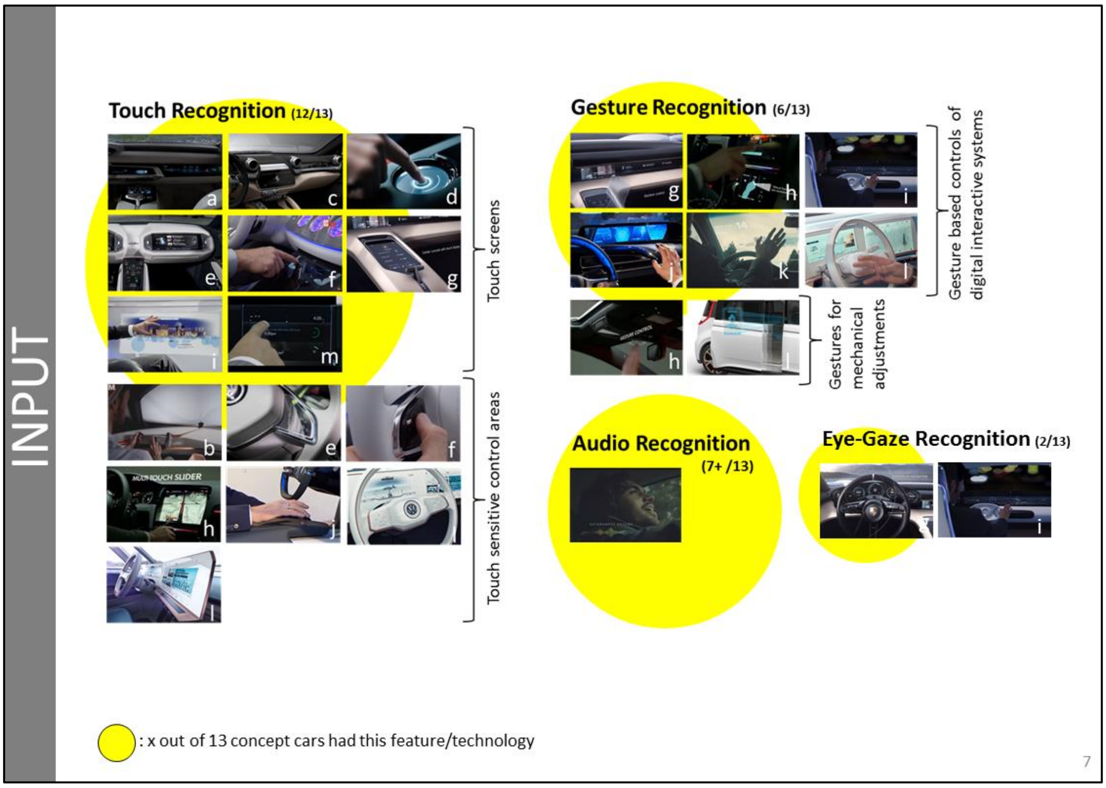
TECHNOLOGY REVIEW:

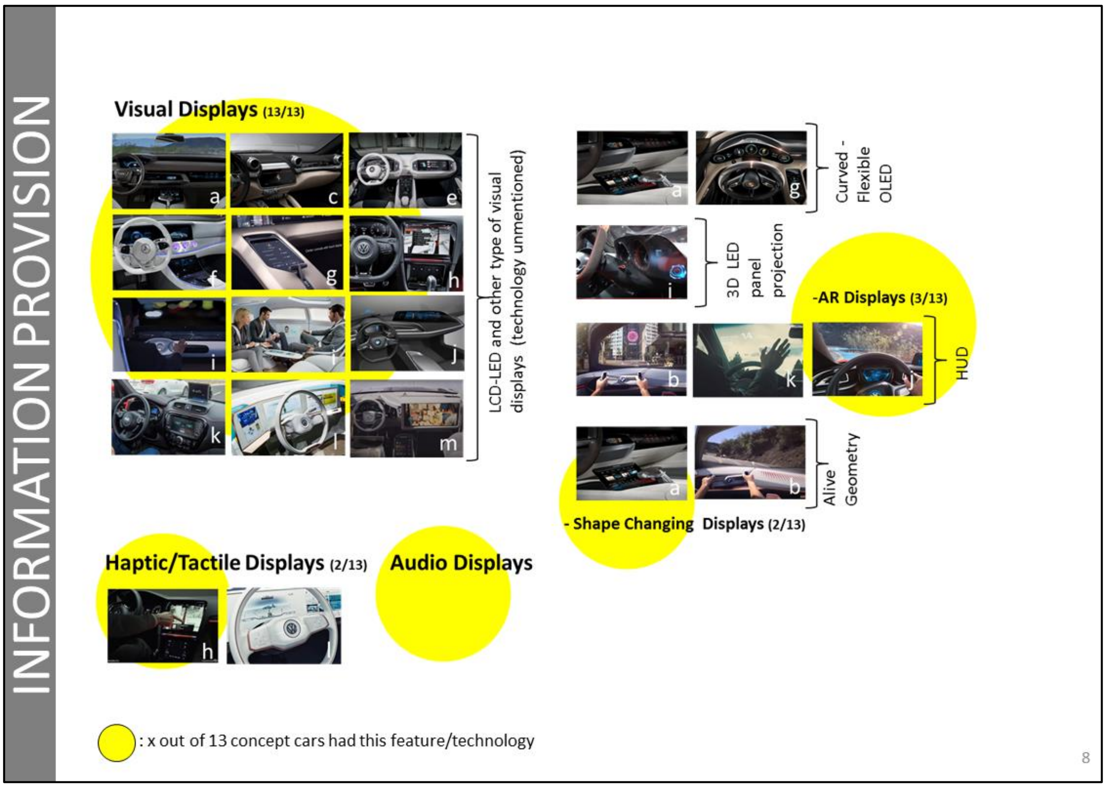
CONCEPT CARS

4

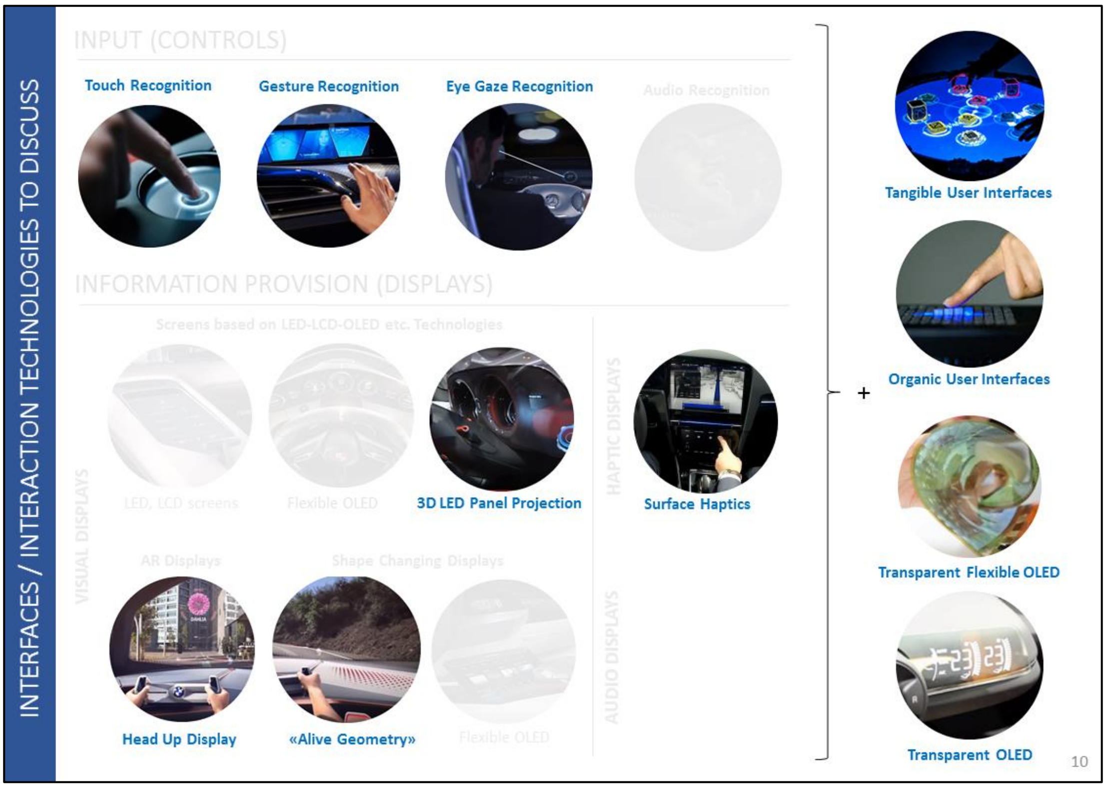

CONCEPT CARS
a. Audi Prologue
(Geneva Motor Show, 2015)
e. Skoda VisionS
(Geneva Motor Show, 2016)
i. Mercedes F015 Luxury in Motion
(CES 2015)
m. Volvo Concept 26
(CES 2016)
THE NEXT 100 YEARS
b. BMW Vision Next 100
(Geneva Motor Show, 2016)
f. Mercedes IAA Concept
(Frankfurt Motor Show, 2015)
j. BMW i8 Vision
(CES 2016)
c. Ferrari GTC 4 Lusso
(Geneva Motor Show, 2016)
g. Porsche Mission E
(Frankfurt Motor Show, 2015)
k. KIA DriveWise
(CES 2016)
d. Opel GT Concept
(Geneva Motor Show, 2016)
h. Volkswagen Golf R Touch
(CES 2015)
l. Volkswagen BUDD-E Concept
(CES 2016)
5


TRENDS
Touch as the most used modality (12/13)
Touch screens
Touch sensitive control areas
Expansion in areas and ways of information provision (10/13)
Screens in whole dashboard and other interior surfaces
HUD on whole windshield
Alive Geometry
Non-autonomous cars
Cars with autonomous mode
Increasing integration of gestural recognition (6/13)
Non-autonomus cars
Cars with autonomous mode
Gesture based controls of digital interactive systems
Gestures for mechanical adjustments
Co-located Physical & Digital Layers of Info (4/13)
Co-location of physical controls and digital feedback
HUD
Curved displays blending into interior (4/13)
Expansion of control areas from dashboard/central console to whole interior (2/13)
6


INPUT
Touch Recognition (12/13)
Touch screens
Touch sensitive control areas
MULTI-TOUCH SLIDER
Gesture Recognition (6/13)
Gesture based controls of digital interactive systems
Gestures for mechanical adjustments
Audio Recognition (7+ /13)
Eye-Gaze Recognition (2/13)
: x out of 13 concept cars had this feature/technology
7


INFORMATION PROVISION
Visual Displays (13/13)
LCD-LED and other type of visual displays (technology unmentioned)
Curved - Flexible OLED
3D LED panel projection
-AR Displays (3/13)
HUD
Alive Geometry
- Shape Changing Displays (2/13)
Haptic/Tactile Displays (2/13)
Audio Displays
: x out of 13 concept cars had this feature/technology
8


INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS
INPUT (CONTROLS)
Touch Recognition
Gesture Recognition
Eye Gaze Recognition
Audio Recognition
INFORMATION PROVISION (DISPLAYS)
VISUAL DISPLAYS
Screens based on LED-LCD-OLED etc. Technologies
LED, LCD screens
Flexible OLED
3D LED Panel Projection
AR Displays
Head Up Display
Shape Changing Displays
«Alive Geometry»
Flexible OLED
HAPTIC DISPLAYS
Surface Haptics
AUDIO DISPLAYS
+
Tangible User Interfaces
Organic User Interfaces
Transparent Flexible OLED
Transparent OLED
9


INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS
INPUT (CONTROLS)
Touch Recognition
Gesture Recognition
Eye Gaze Recognition
Audio Recognition
INFORMATION PROVISION (DISPLAYS)
VISUAL DISPLAYS
Screens based on LED-LCD-OLED etc. Technologies
LED, LCD screens
Flexible OLED
3D LED Panel Projection
AR Displays
Head Up Display
Shape Changing Displays
«Alive Geometry»
Flexible OLED
HAPTIC DISPLAYS
Surface Haptics
AUDIO DISPLAYS
+
Tangible User Interfaces
Organic User Interfaces
Transparent Flexible OLED
Transparent OLED
10

INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS

TOUCH RECOGNITION

BMW i8 Vision Future Interactions (CES 2016) has a touch sensitive armrest with the sensors placed under its leather upholstery.

Touch recognition can be achieved through electrical (resistive and capacitive), surface wave (ultrasonic), and optical (e.g. infrared) systems (Saffer, 2009)

11

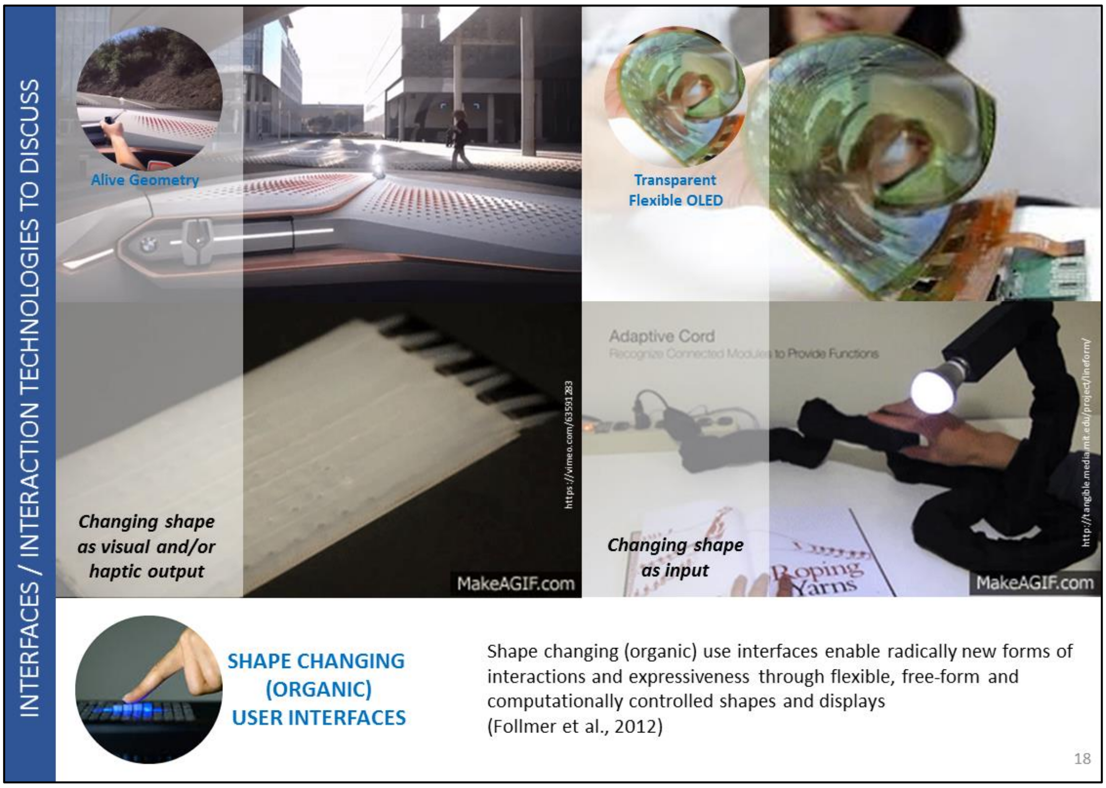
INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS

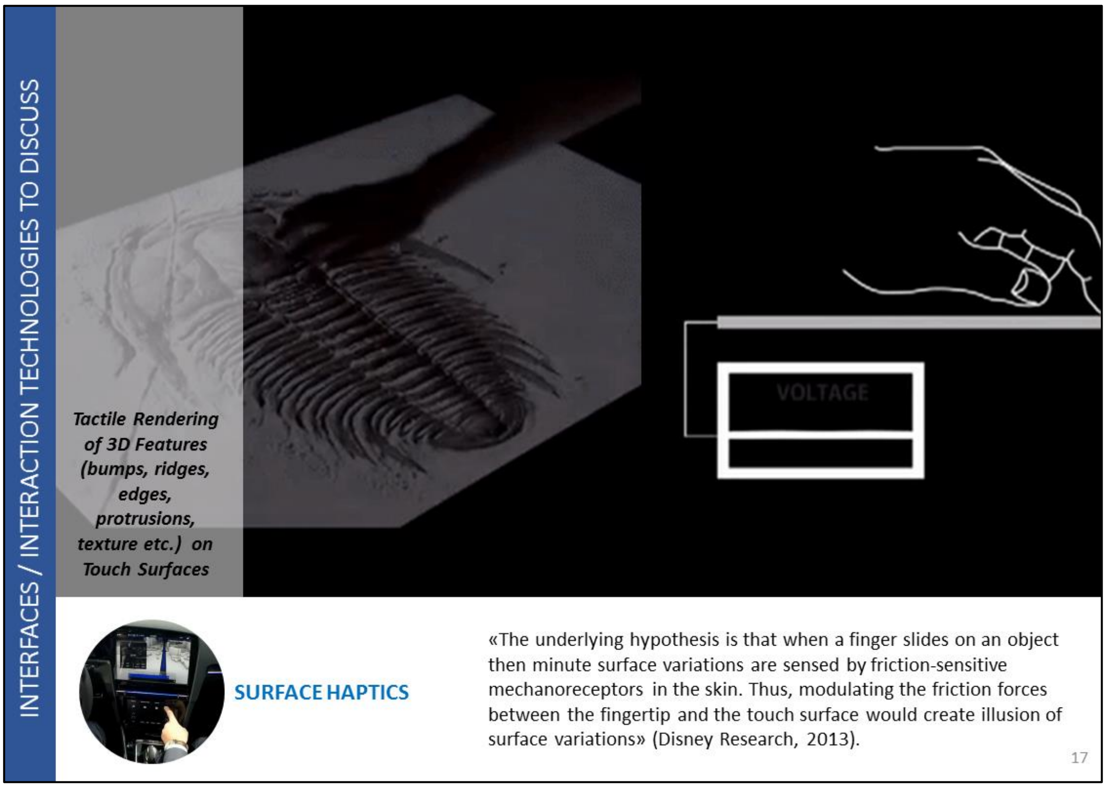
GESTURE RECOGNITION

Gesture recognition (supported by eye-gaze recognition) to control dashboard displays in Mercedes F015 Luxury in Motion (CES 2015)

Gesture recognition can be achieved through camera-based systems (e.g. time of flight, stereo) and/or proximity sensors (e.g. capacitive).

12


INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS
Alive Geometry
Transparent
Flexible OLED
Changing shape
as visual and/or
haptic output
https://vimeo.com/63591283
MakeAGIF.com
Adaptive Cord
Changing shape
as input
http://tangible.media.mit.edu/project/lineform/
MakeAGIF.com
SHAPE CHANGING
(ORGANIC)
USER INTERFACES
Shape changing (organic) use interfaces enable radically new forms of interactions and expressiveness through flexible, free-form and computationally controlled shapes and displays
(Follmer et al., 2012)
18


INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS
Tactile Rendering
of 3D Features
(bumps, ridges,
edges,
protrusions,
texture etc.) on
Touch Surfaces
VOLTAGE
SURFACE HAPTICS
«The underlying hypothesis is that when a finger slides on an object then minute surface variations are sensed by friction-sensitive mechanoreceptors in the skin. Thus, modulating the friction forces between the fingertip and the touch surface would create illusion of surface variations» (Disney Research, 2013).
17

INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS

HEAD UP DISPLAY

HUD in BMW Vision Next 100 (Geneva Motor Show, 2016)

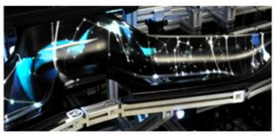
«The BMW HUD system uses a small projector and a system of mirrors to beam high-contrast images onto a translucent film on the windscreen. Images are projected directly into the driver's line of sight, and appear about two meters away, making them easy to read & process.» (Herb Chambers BMW, n.d.)

16

INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS

turning any 3D surface into display through backlit projection

3D LED PANEL PROJECTİON



15

INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS

TRANSPARENT OLED

Panasonic Transparent Display TV (CES 2016) (top)
KIA GT concept with T-OLED dashboard (Frankfurt Motor Show, 2011) (left)

Transparent OLED screen technology uses self-lighting LEDs on a transparent substrate - no need for backlighting to create stunning AV & digital signage (Prodisplay, 2018)

14

INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS

EYE GAZE RECOGNITION

Porsche Mission E (Frankfurt Motor Show, 2015) with a stereoscopic instruments display where the position and size of the icons change according to eye-gaze.

Eye gaze recognition can be achieved through the corneal reflection method (infrared light projection to/reflection from the eye) or video-based systems (processing the contrast of the white of the eye and the dark iris) (Drewes, 2010)

13

INTERFACES / INTERACTION TECHNOLOGIES TO DISCUSS

« giving physical form to digital information by utilizing physical artefacts both as representations and controls of computational media» (Ishii and Ullmer, 2001)

TANGIBLE USER INTERFACES

Reactable: Creating a musical composition by manipulating physical objects representing e.g. synthesisers, effects, samples and control on a digital surface that displays sonic flows and connections among the objects.

Tangible user interfaces can be based on RFID technology, computer vision or combination of sensors-microcontrollers-actuators.

19

APPENDIX 6. Participant recruitment advertisement (VR simulation)

UNIVERSITY OF LIVERPOOL

School of Engineering | Division of Industrial Design

Virtual Reality (VR) Simulation of Front-Seat Passenger Infotainment System

PARTICIPANTS NEEDED FOR A USER STUDY

Fancy trying a virtual reality simulation?

Come and experience the passenger-oriented automotive user interfaces of future!

in collaboration with VIRTUAL ENGINEERING CENTRE

We are looking for participants to take part in one session lasting **approximately 1 hour.** The session will be held **in Virtual Engineering Centre, Daresbury Science Park.**

In this session, you will experience a 15-minutes-demonstration of a new front-seat passenger infotainment system by wearing a VR headset. During this demonstration, you will be introduced several infotainment features within a travel scenario and asked to perform simple interaction tasks with mostly hand gestures. Then you will complete a short questionnaire and share your opinions about the system in an interview.

To take part, you should:

- Travel as a car passenger (preferably in a high-end car) in daily life. You can be drivers yourselves as well, but you will take part in the study for your experience as a car passenger.
- Be at least 18 years old.

The risk of «simulator sickness» is minimized since the virtual environment will be static, you will be seated during VR demo and it will take max. 15 minutes. However, you <u>should not</u> take part if you are oversensitive to activities that might create motion sickness.

If interested, please contact **Guzin Sen** at **guzinsen@liverpool.ac.uk**

VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk	VR simulation – User Study guzinsen@liv.ac.uk

APPENDIX 7. Participant information sheet (VR simulation)

UNIVERSITY OF LIVERPOOL

Virtual Reality (VR) Simulation of Front-Seat Passenger Infotainment System

[Version 2, November 2017]

You are being invited to participate in a research study. Before you decide whether to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and feel free to ask us if you would like more information or if there is anything that you do not understand. We would like to stress that you do not have to accept this invitation and should only agree to take part if you want to. Thank you for reading this.

Purpose of the study:

This study is conducted as a part of PhD research “Empowering Front-Seat Passenger: Design and Prototyping of Luxury Infotainment Interactions through Simulation” in collaboration with Virtual Engineering Centre and Bentley Motors. The term “infotainment” refers to the interactive systems that provide information and entertainment services (e.g. navigation, media) to passengers and / or drivers on board. When we look at automotive user interfaces, we see that these interactive systems are designed within the limitations of driving activity. In other words, the potentials of interaction technologies to enhance front-seat passenger's journeys are underestimated. This PhD research aims to investigate new infotainment features and interactions specifically for front-seat passengers in the context of a luxury car.

This study will demonstrate a prototype of a front-seat passenger infotainment system in an interactive and immersive virtual reality (VR) environment. As participant of this study you are expected to wear a virtual reality headset and interact with the virtual content with hand gestures and a touch-sensitive button provided. Before VR demo, you will fill a small simulation sickness questionnaire so we can understand if you already feel any discomfort / sickness before wearing VR headset. Then there will be warm-up session for you to get used to the VR equipment and interacting with the system before the demonstration of the infotainment system.

During VR demonstration, you will be introduced several infotainment features (e.g. media menu) within a travel scenario and asked to perform simple interaction tasks (e.g. selection of a menu item, scrolling through a list). The student researcher will be sitting next to you during the demonstration as a narrator of the travel scenario. She will explain the next interaction task in each step and provide any guidance you need. The student researcher will be able to observe what you are doing in virtual environment through another display connected to the headset. The demonstration will be followed by two small questionnaires. In first one, you will rate the discomfort that can be caused by VR headset. In second one, you will be asked to evaluate your experience of the infotainment system. The study will conclude with an interview, which will enable you to explain the reasons behind your evaluations and share your opinions and/or suggestions about the system further.

Through the analysis of the user experience evaluation questionnaire and the follow-up interview, this study aims to investigate in what ways a pleasant front-seat passenger infotainment experience is linked with varied aspects of interactions (HOW you interact with the system) and new infotainment features (WHAT you can do thanks the system).

1/3

Participants of the study:
You are invited to this study as a person who travels as a car passenger in daily life since we would like to prototype the interactions with a front-seat passenger infotainment system in VR and find out how this system may enhance your journeys as front-seat passengers. To take part you should be at least 18 years old and not be over-sensitive to activities that might create motion sickness.

We would like to remind that participation is voluntary and that participants are free to withdraw at any time without explanation and without incurring a disadvantage.

Structure of the study:
This PhD research is conducted by the PhD student Guzin Sen under the supervision of Dr. Mike Jump and Dr Bahar Sener-Pedgley. This study will be led by Guzin Sen and the whole session is expected to take ***approximately 1 hour***. It consists of following steps:

1. Questionnaire	***(app. 2 mins)***
Filling in a simulation sickness questionnaire, so we can understand if you feel any discomfort before using VR headset.	
2. Warm-up Session	***(app. 5 mins)***
Getting used to the VR equipment (VR headset) and interacting with the system (using hand gestures and the touch sensitive button provided) before the demonstration of the front-seat passenger infotainment system.	
3. VR Demonstration of Front-Seat Passenger Infotainment Interactions	***(app. 15 mins)***
Being introduced several infotainment features (e.g. media menu) within a travel scenario and asked to perform simple interaction tasks (e.g. selection of a menu item, scrolling through a list) as a front-seat passenger	
4. Questionnaire	***(app. 2 mins)***
Filling in the simulation sickness questionnaire again, so we can understand if using VR headset caused any discomfort.	
5. User Experience Evaluation and Follow-up Interview	***(app. 35 mins)***
Filling in a small questionnaire where you will be asked to rate your experience of the infotainment system; discussing the reasons behind your evaluation and sharing your opinions and/or suggestions about the system further in an interview. **Note:** We will provide you a visual presentation of the interaction steps you will have gone through in VR demonstration. You will be able to refer to those visuals while reflecting on your experience.	

Risks in taking part:
The risks in taking part may include “simulation / simulator sickness” - "a form of induced motion sickness that results from the conflicts between the visual and bodily senses" (Oculus Developers, 2017). You may also experience discomfort while wearing the headset. However, in this study these risks are minimized. The virtual car and the environment will be static. You will be seated during the VR demonstration and the following steps. The duration of the VR demonstration is kept as maximum 15 minutes. As participants, you are free to take breaks during simulation or decide not to take part

whenever you want. The student researcher will be there to assist you.

Oculus Developers (2017). Simulator Sickness. Retrieved on September 21, 2017, from https://developer.oculus.com/design/latest/concepts/bp_app_simulator_sickness/

What if I am unhappy or if there is a problem?

If you are unhappy, or if there is a problem, please feel free to let us know by contacting the principal investigator/supervisor Dr Mike Jump (see contact details below) and we will try to help. If you remain unhappy or have a complaint which you feel you cannot come to us with then you should contact the Research Governance Officer at ethics@liv.ac.uk. When contacting the Research Governance Officer, please provide details of the name or description of the study (so that it can be identified), the researcher(s) involved, and the details of the complaint you wish to make.

Benefits in taking part:

There is no immediate benefit for participants other than experiencing virtual reality in a new context and learning about the development process of future passenger-oriented automotive user interfaces.

Will my participation be kept confidential? What will happen to the results of the study?

A video and voice recorder will be used to capture all the interactions performed and all comments made during the session. We will refer to the video recordings to clarify which part of your experience you pointed out in the interview and to see if there are any common design issues observed in participants' interactions with the system. After the session, the student researcher (Guzin Sen) will collect all hand-filled hard copy documents and safely store them within her locked file cabinet at the office. All digital data will be transferred to UoL M-Drive and safely secured. Your identity will be anonymised on the completion of the study session (e.g. Participant 1) for data arrangement and presentation of results. The data will be only available to the student researcher and supervisor until the end of PhD research (28 FEB 2019). The data / meta-data (descriptive information) will then be archived in data repository of the university for 10 years as required by the funder of the research, then all data will be permanently destroyed/deleted. The findings of this study can be used in research reports, conference presentations, publications and the PhD dissertation. The feedback on the findings of the study can be shared with you at your request in the format of a written report.

For further information:

Principal Investigator / Supervisor
Dr Mike Jump
Mjump1@liverpool.ac.uk

Mechanical, Materials & Aerospace Engineering
School of Engineering, University of Liverpool
Walker Building, Room UG32
L69 3GH, Liverpool, UK

Student Researcher
Guzin Sen
guzinsen@liverpool.ac.uk

Division of Industrial Design
School of Engineering, University of Liverpool
Brodie Tower, Room 205
L3 5DA, Liverpool, UK

APPENDIX 8. Participant consent form (VR simulation)

UNIVERSITY OF LIVERPOOL

Committee on Research Ethics

PARTICIPANT CONSENT FORM

Title of Research Project:	Virtual Reality (VR) Simulation of Front-Seat Passenger Infotainment System
Researcher(s):	Dr. Mike Jump (Supervisor) Dr. Bahar Sener-Pedgley (Supervisor) Guzin Sen (Student Researcher)

Please initial box

1. I confirm that I have read and have understood the information sheet dated [November 2017] for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. In addition, should I not wish to answer any particular question or questions, I am free to decline.

3. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish.

4. I understand and agree that my participation will be audio and video recorded and I am aware of and consent to your use of these recordings in the analysis of the study. The audio and video recordings will only be available to the student researcher and the supervisors and will not be shared with third parties.

5. I understand that I must not take part if I am oversensitive to activities that might create motion sickness.

6. I understand and agree that what I have said or written as part of this study will be used in reports, publications and other research outputs where my identity will be anonymised (e.g. Participant 1).

7. I agree to take part in the above study.

Participant Name   Date   Signature

Researcher/ Name of Person taking consent   Date   Signature

Principal Investigator / Supervisor
Dr. Mike Jump
Mjump1@liverpool.ac.uk

Mechanical, Materials & Aerospace Engineering
School of Engineering, University of Liverpool
Walker Building, Room UG32
L69 3GH, Liverpool, UK

Student Researcher
Guzin Sen
guzinsen@liverpool.ac.uk

Division of Industrial Design
School of Engineering, University of Liverpool
Brodie Tower, Room 205
L3 5DA, Liverpool, UK

[Version 2 & November 2017]

APPENDIX 9. The narrative of the VR simulation

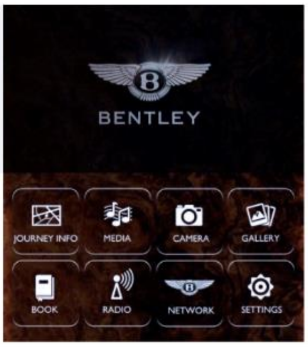
VR simulation of the front-seat passenger infotainment system

INTERACTION SCENARIO

<table>
<tr>
<td>

1.Activation & Main Menu

Panorama 1



</td>
<td>

Activation-deactivation, highlighting (following the point), selection, scrolling, volume control...

Not all buttons are active however I will narrate the interaction scenario and tell the next task every time.

"You are now sitting in front-seat passenger's seat of a Bentley GT. You spent your Saturday in a luxury spa-hotel, it is a sunny Sunday morning and you will now start your journey back home.

- You can now activate the infotainment system by pushing the button on armrest, you will see several infotainment menu options, and you will be interacting with some of them in this journey.

</td>
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<td>

2. Camera

Panorama 2

</td>
<td>

PRESS #2: Panorama 1 >>> Panorama 2

"After a little while, you are passing through a cute historical town in Burford. You would like to take a picture of your view."

- You can now select the camera menu from the home menu.
- If you point at the shutter icon in the middle until it turns into orange you can shoot the photo.
- You can now close the camera menu by pointing at back icon.

</td>
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<tr>
<td>

3. Journey Info

Panorama 3

</td>
<td>

PRESS #3: Panorama 2 >>> Panorama 3

"You have been travelling for a while, you are wondering where you are and how much time left for the next destination."

- You can now select the journey info menu from the home menu.
- You can go through each destination point by pointing at it. For each destination you can view the address; it's location on the map, arrival time, the weather forecast and a picture for that destination as a background. Please take time to view the menu.
- Can you see the picture you have just taken?
- You can return to home menu by pointing at the home icon.

</td>
</tr>
</table>

1/3

4. Book

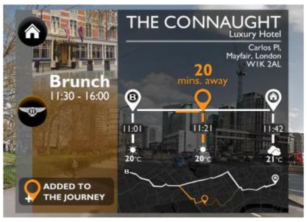
Panorama 3

"Since there is still time to arrive in your next destination, you decide to read something".

- You can now select the book menu from the home menu
- It opens with the last page you were reading.
- You can scroll through the page and skip to other pages again by using the bar at the bottom.
- Enough with the reading! You can close the menu by pointing at the back button

5. Event suggestion

Panorama 4



PRESS #4: Panorama 3 >>> Panorama 4

"You are now much closer to your final destination."

PRESS N

"After a while a notification pops up on head-up display. It is an event suggestion by the Bentley Network application. There is a brunch event in a luxury hotel in Mayfair, London which is only 20 minutes away. Please take time to view the menu."

- You add this destination to your journey by pointing at the button on the left.
- You can close the notification now.

6. Media

Panorama 4

"Let's listen to music in remaining time"

- You can select the media menu
- You can scroll down on the playlist on the left. You can see which song will be playing when you arrive at the hotel.
- Pick a song and point at it for a while to play.
- You can adjust the volume either with the gesture or by swiping on the touch sensitive button.

<table>
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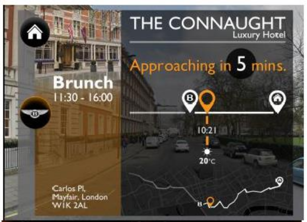
<td>

7. Approaching Notification

Panorama 5



</td>
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PRESS #5: Panorama 4 >>> Panorama 5

PRESS N

"Another notification by Bentley Network application appears on head-up display. There is only 5 minutes left to the hotel"

- You can close the notification

"You would like to take this time get ready for alighting (getting of the car), so you decide to pause the song and go back to home menu."

- You can now pause the song and turn back to home menu.

</td>
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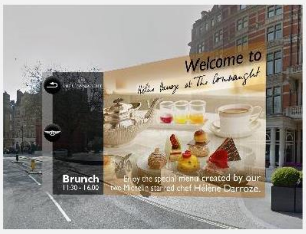
<tr>
<td>

8. Arrival Notification

Panorama 6



</td>
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PRESS #6: Panorama 5>>> Panorama 6

"You have just arrived in Mayfair area and trying to remember or find out which building is The Connaught Hotel."

PRESS N

"The hotel greets you with a notification. You can see what is waiting for you at the brunch."

- Take time to review the notification. Then you can close it by pointing at the back button.

</td>
</tr>
<tr>
<td>

9. Deactivation

</td>
<td>

"Do you see the other luxury cars parked in front of the hotel?" "It is time to leave the car and enjoy the brunch"

- You can deactivate the infotainment system by pressing the button on the armrest.
- You can now take off the VR headset.

</td>
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</table>

APPENDIX 10. Simulation sickness questionnaire (SSQ) (formatted)

Date:
Participant No:
Questionnaire No:

UNIVERSITY OF LIVERPOOL

Virtual Reality (VR) Simulation of Front-Seat Passenger Infotainment System

Participant Information

Participant Name-Surname:
Age:
Gender:

SIMULATION SICKNESS QUESTIONNAIRE (Kennedy, Lane, Berbaum, & Lilienthal, 1993)

Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

APPENDIX 11. Presence questionnaire (original)

PRESENCE QUESTIONNAIRE

(Witmer & Singer, Vs. 3.0, Nov. 1994)*
Revised by the UQO Cyberpsychology Lab (2004)

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT

1. How much were you able to control events?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

2. How responsive was the environment to actions that you initiated (or performed)?

|________|________|________|________|________|________|________|

NOT RESPONSIVE MODERATELY RESPONSIVE COMPLETELY RESPONSIVE

3. How natural did your interactions with the environment seem?

|________|________|________|________|________|________|________|

EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

4. How much did the visual aspects of the environment involve you?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

5. How natural was the mechanism which controlled movement through the environment?

|________|________|________|________|________|________|________|

EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

6. How compelling was your sense of objects moving through space?

|________|________|________|________|________|________|________|
NOT AT ALL MODERATELY COMPELLING VERY COMPELLING

7. How much did your experiences in the virtual environment seem consistent with your real world experiences?

|________|________|________|________|________|________|________|
NOT CONSISTENT MODERATELY CONSISTENT VERY CONSISTENT

8. Were you able to anticipate what would happen next in response to the actions that you performed?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

9. How completely were you able to actively survey or search the environment using vision?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

10. How compelling was your sense of moving around inside the virtual environment?

|________|________|________|________|________|________|________|
NOT COMPELLING MODERATELY COMPELLING VERY COMPELLING

11. How closely were you able to examine objects?

|________|________|________|________|________|________|________|
NOT AT ALL PRETTY CLOSELY VERY CLOSELY

12. How well could you examine objects from multiple viewpoints?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT EXTENSIVELY

13. How involved were you in the virtual environment experience?

|________|________|________|________|________|________|________|
NOT INVOLVED — MILDLY INVOLVED — COMPLETELY ENGROSSED

14. How much delay did you experience between your actions and expected outcomes?

|________|________|________|________|________|________|________|
NO DELAYS — MODERATE DELAYS — LONG DELAYS

15. How quickly did you adjust to the virtual environment experience?

|________|________|________|________|________|________|________|
NOT AT ALL — SLOWLY — LESS THAN ONE MINUTE

16. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

|________|________|________|________|________|________|________|
NOT PROFICIENT — REASONABLY PROFICIENT — VERY PROFICIENT

17. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

|________|________|________|________|________|________|________|
NOT AT ALL — INTERFERED SOMEWHAT — PREVENTED TASK PERFORMANCE

18. How much did the control devices interfere with the performance of assigned tasks or with other activities?

|________|________|________|________|________|________|________|
NOT AT ALL — INTERFERED SOMEWHAT — INTERFERED GREATLY

19. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

|________|________|________|________|________|________|________|
NOT AT ALL — SOMEWHAT — COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED SOUNDS:

20. How much did the auditory aspects of the environment involve you?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

21. How well could you identify sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

22. How well could you localize sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED HAPTIC (SENSE OF TOUCH):

23. How well could you actively survey or search the virtual environment using touch?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

24. How well could you move or manipulate objects in the virtual environment?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT EXTENSIVELY

Last version : March 2013

*Original version : Witmer, B.G. & Singer. M.J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence : Teleoperators and Virtual Environments*, 7(3), 225-240. Revised factor structure: Witmer, B.J., Jerome, C.J., & Singer, M.J. (2005). The factor structure of the Presence Questionnaire. *Presence, 14*(3) 298-312.

Questionnaire sur l'État de Présence (QÉP)
Laboratoire de Cyberpsychologie de l'UQO

Validation of the French-Canadian version developed by the UQO Cyberpsychology Lab:

- 101 participants completed the questionnaire following an immersion in a virtual environment;
- Cronbach's Alpha = .84
- Now 19 items (for VEs without sound/touch) et 24 items (for VEs with sounds/touch)

Scoring :

Total : Items 1 to 19 (reverse items 14, 17, 18)

- « Realism » : Items 3 + 4 + 5 + 6 + 7 + 10 + 13
- « Possibility to act » : Items 1 + 2 + 8 + 9
- « Quality of interface » : Items (all reversed) 14 + 17 + 18
- « Possibility to examine » : Items 11 + 12 + 19
- « Self-evaluation of performance » : Items 15 + 16
- « Sounds* » : Items 20 + 21 + 22
- « Haptic* » : Items 23 + 24

* NOTE : Scoring of « *sounds* » and « *haptic* » are not part of the factor analysis of the French version.

Norms (French version) :

	Moyenne	**Écart type**
Total	104.39	18.99
« Realism »	29.45	12.04
« Possibility to act »	20.76	6.01
« Quality of interface »	15.37	5.15
« Possibility to examine»	15.38	4.90
« Auto-évaluation de la performance »	11.00	2.87

Last version : March 2013

*Original version : Witmer, B.G. & Singer. M.J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence : Teleoperators and Virtual Environments*, *7*(3), 225-240. The factor structure of the Presence Questionnaire. *Presence, 14*(3) 298-312. Revised factor structure: Witmer, B.J., Jerome, C.J., & Singer, M.J. (2005). The factor structure of the Presence Questionnaire. *Presence, 14*(3) 298-312.

APPENDIX 12. Presence questionnaire (PQ) (formatted)

Date:
Participant No:

UNIVERSITY OF LIVERPOOL

Virtual Reality (VR) Simulation of Front-Seat Passenger Infotainment System

Participant Information

Participant Name-Surname:
Age:
Gender:

PRESENCE QUESTIONNAIRE (SIMULATION EVALUATION)

Characterize your experience in the virtual environment, by marking an "X" in the appropriate circle of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply.

1. How natural did your interactions with the environment seem?

O O O O O O O

extremely artificial | borderline | completely natural

2. How involved were you in the virtual environment experience?

O O O O O O O

not at all | somewhat | completely

3. How much did your experiences in the virtual environment seem consistent with your real world experiences?

O O O O O O O

not consistent | moderately consistent | very consistent

4. How compelling was your sense of navigating around inside the virtual environment?

O O O O O O O

not compelling | moderately compelling | very compelling

APPENDIX 13. UX evaluation questionnaire (UXQ)

Date:
Participant No:

UNIVERSITY OF LIVERPOOL

Virtual Reality (VR) Simulation of Front-Seat Passenger Infotainment System

Participant Information

Participant Name-Surname:
Age:
Gender:

QUESTIONNAIRE (USER EXPERIENCE EVALUATION)

Please select the option (one of the seven circles for each pair of words/phrases) that best describes your experience of this front-seat passenger infotainment system:

complicated	○	○	○	○	○	○	○	simple
cumbersome	○	○	○	○	○	○	○	efficient
unruly	○	○	○	○	○	○	○	manageable
unpredictable	○	○	○	○	○	○	○	predictable
conservative	○	○	○	○	○	○	○	innovative
usual	○	○	○	○	○	○	○	extraordinary
cautious	○	○	○	○	○	○	○	bold
dull, unimaginative	○	○	○	○	○	○	○	captivating
alienating	○	○	○	○	○	○	○	involving
low quality, unrefined	○	○	○	○	○	○	○	high quality, refined
tacky	○	○	○	○	○	○	○	stylish
unpresentable	○	○	○	○	○	○	○	presentable

"My infotainment experience fails to answer my expectations from a luxury car."	○	○	○	○	○	○	○	"My infotainment experience answers my expectations from a luxury car."

APPENDIX 14. UX evaluation interview questions

Virtual Reality Simulation of Front-Seat Passenger Infotainment System

INTERVIEW QUESTIONS

---

1. What made you think that your experience is more [semantic differential] than [semantic differential]? What aspects of interactions affected your decisions the most?

   - **Sensory-specific Aspects:** Because of the way the infotainment system looks/sounds/feels at hand?
   - **Temporal Aspects:** Because of the duration/speed/rhythm of …?
   - **Action-Reaction Aspects:** Because of the way the infotainment system responds to your actions?
   - **Presentation Aspects:** Because of the way the infotainment system invites/guides you to control?
   - **Functionality/Content**: Is it about the infotainment feature/task itself?
   - **Context:** Because of the context (environment, presence of the driver etc.)?

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2. How was your overall experience? Let's review all the interaction steps you have gone through from the boards. What do you think can be improved / what would you change (to make it easier to use, more functional, more entertaining, more social (involving)?

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3. If you had such system (a head up display that can display digital images and animations as an addition to your windscreen (windshield) view, another display on passenger dashboard, gesture control, and a physical controller on your armrest ready at hand) in a car:

   a. Which infotainment features (from the ones that you are offered) do you see yourself using the most/least?

   b. What other infotainment features would you like to see? What other activities would you use it for?

      - What other communication options (in addition to Bentley Network notifications)? It can be about the communication with the other car occupants or other people.
      - What other entertainment options (in addition to camera, book and media provided)?
      - What other information options (in addition to journey info and Bentley Network notifications)?

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4. Thinking of your previous «passengering» experiences, in what ways do you think this system can improve your journeys? Is there anything in this system that would make your in-car activities easier, more entertaining or more social?

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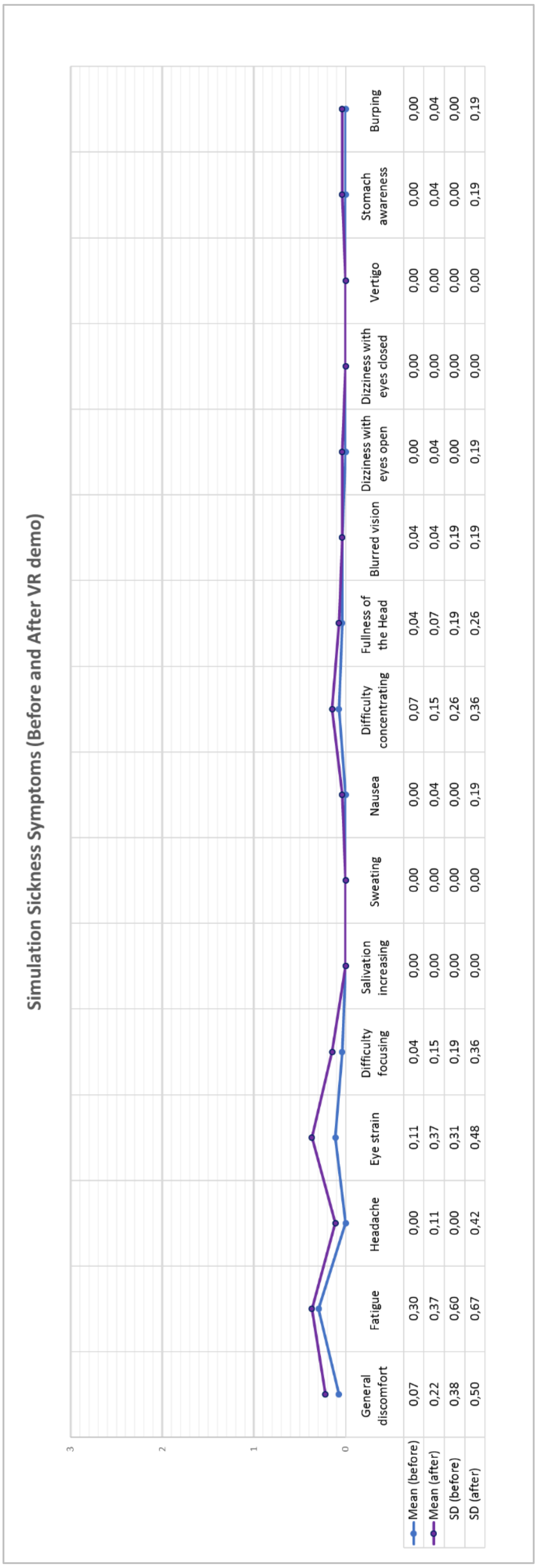
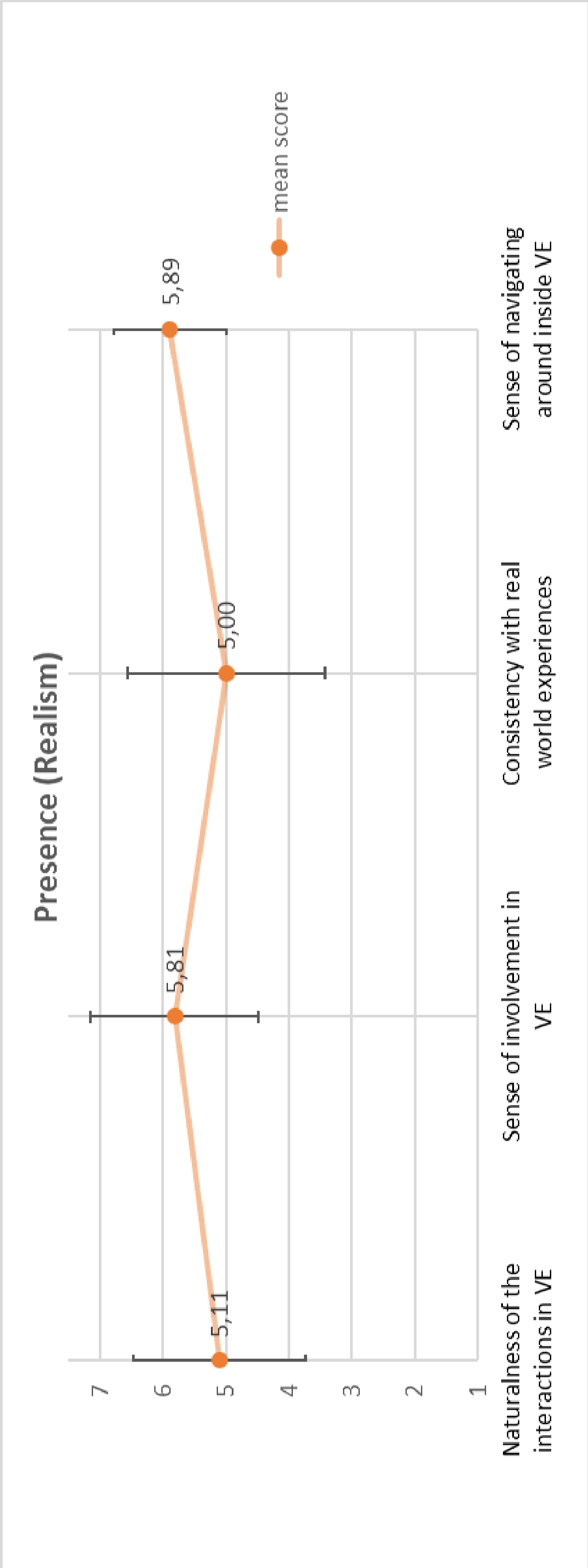
5. Thinking of your previous «passengering» experiences, what can go wrong in this system?

APPENDIX 15. SSQ results (before and after VR demo)



	General discomfort	Fatigue	Headache	Eye strain	Difficulty focusing	Salivation increasing	Sweating	Nausea	Difficulty concentrating	Fullness of the Head	Blurred vision	Dizziness with eyes open	Dizziness with eyes closed	Vertigo	Stomach awareness	Burping
Mean (before)	0,07	0,30	0,00	0,11	0,04	0,00	0,00	0,00	0,07	0,04	0,04	0,00	0,00	0,00	0,00	0,00
Mean (after)	0,22	0,37	0,11	0,37	0,15	0,00	0,00	0,04	0,15	0,07	0,04	0,04	0,00	0,00	0,04	0,04
SD (before)	0,38	0,60	0,00	0,31	0,19	0,00	0,00	0,00	0,26	0,19	0,19	0,00	0,00	0,00	0,00	0,00
SD (after)	0,50	0,67	0,42	0,48	0,36	0,00	0,00	0,19	0,36	0,26	0,19	0,19	0,00	0,00	0,19	0,19

APPENDIX 16. PQ results



APPENDIX 17. Total SSQ (before/after VR demo), UXQ and PQ scores (in percentages) for each participant